Recurrence Arrhythmias Quantification Analysis Using Simultaneous Optical and Electrical Cardiac Recordings”

Introduction: Cardiac arrhythmias produce complex, non-stationary signals that challenge conventional electrophysiological analysis. Recurrence Quantification Analysis (RQA) addresses this by characterizing signal dynamics without stationarity assumptions. This study applies RQA metrics for arrhythmia classification in simultaneous electrical and optical recordings.

Methodology: Optical-OPT (ΔF/F, 500 Hz) and electrical-ELE (0.5 - 250 Hz bandpass, down sampled to 500 Hz) recordings were acquired from isolated rabbit hearts. Sinus rhythm (SR), atrial tachycardia (AT), ventricular tachycardia (VT), monomorphic VT (MVT) and ventricular fibrillation (VF) were induced using S1-S2 protocol and burst pacing after carbachol (1 μM) infusion. RQA was applied using time-delay embedding (τ: 4; m: 4) at 10% recurrence rate, extracting determinism (DET: signal regularity), laminarity (LAM: state persistence), and entropy (ENT: complexity) over 1 s, 3 s, and 5 s windows. Statistical comparisons used Kruskal–Wallis tests with Bonferroni-corrected post hoc analysis.

Results: Segments between 3 s and 5 s characterized equivalent dynamics rather than 1 s. For atria rhythms, electrical and optical LAM/DET differed SR and AT (LAM_{ELE}: η^2=0.45 and DET_{ELE}: η^2=0.29, $p<0.001$; LAM_{OPT}: η^2=0.65 and DET_{OPT}: η^2= 0.60, $p<0.001$), showing less organization (DET) and stability over time (LAM) during AT. For ventricular rhythms, LAM differed significantly across all rhythm pairs (η^2=0.85, $p<0.001$), except for LAM_{OPT} that could not differ between VT vs MVT ($p=0.15$). $DET_{OPT\ and\ ELE}$ and $ENT_{OPT\ and\ ELE}$ differed significantly VT vs. VF and MVT vs. VF, reflecting increased signal complexity (ENT) during fibrillation.

Conclusion: Optical and electrical signals acquired simultaneously allow better arrhythmia characterization using RQA. LAM could differentiate between all rhythms in both modalities, making it the strongest discriminator. DET reflected regularity changes, with optical signals separating rhythms electrical signals could not. ENT revealed fibrillation complexity, with optical recordings providing broader separation.