# Deep Learning-Based Automated Extraction of Cardiac Time Intervals from Electrocardiogram and Phonocardiogram for Heart Failure Assessment

Mariana Lourenço[1], Cátia Isabel Costa[2], Cristina Oliveira[3], André Lobo[2], Ricardo Fontes-Carvalho[3], Francesco Renna[1]

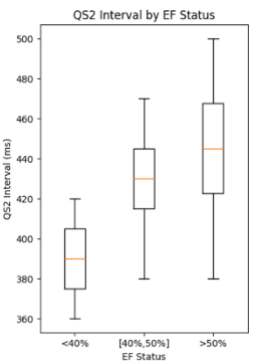
[1] INESC TEC, FCUP, Porto, Portugal
[2] ULSGE, Porto, Portugal
[3] UnIC@RISE, Porto, Portugal

**Aims**: Cardiac Time Intervals (CTIs) are established markers of systolic function and correlate with left ventricular ejection fraction (LVEF), but their clinical assessment typically relies on echocardiography. This work aims to develop a fully automated framework for CTI extraction from synchronous electrocardiogram (ECG) and phonocardiogram (PCG) signals, and to evaluate their ability to discriminate heart failure (HF) phenotypes.

**Methods**: A dataset of 558 ECG–PCG recordings from 167 subjects was analyzed. Two pipelines were implemented: (i) a beat-by-beat approach using U-Net models to segment ECG (P, QRS, T) and PCG (S1, S2) signals from multi-domain features, and (ii) a median heartbeat (MHB) approach, where beats are aligned and aggregated prior to segmentation to improve robustness.

CTIs (QT, QS1, QS2, S1S2) were computed from detected fiducial points, evaluated against manual annotations (n = 84), and analyzed across LVEF-defined groups.

**Results**: The framework achieved good agreement with reference manual annotations (MAE: S1S2=17.3 ms, QS2=46.0 ms). The MHB approach improved robustness and reduced variability, particularly in noisy signals.




QS2 and S1S2 intervals were the most discriminative of HF status, showing significantly shorter values in patients with EF<40% ($p < 0.05$), while not able to discriminate between EF>50% and 40%<EF<50%. QS1 showed moderate sensitivity, while QT provided weaker discrimination.

In contrast to our previous work based on manual annotations, this study enables fully automated CTI extraction via deep learning.

**Conclusions**: Deep learning-based segmentation combined with median heartbeat modeling enables robust, fully automated CTI estimation from ECG–PCG signals. The discriminative power of QS2 and S1S2 supports their use as scalable, low-cost biomarkers for heart failure monitoring.