Natural Visibility Graph–based Analysis of RR Intervals for Atrial Fibrillation Onset Prediction

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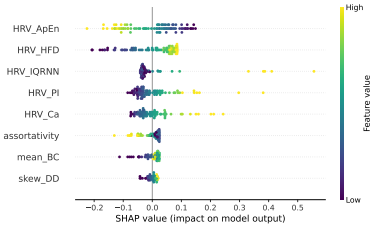
Introduction: The autonomic nervous system (ANS) plays a significant role in triggering and sustaining atrial fibrillation (AF) episodes. ANS activity, reflected in heart rate variability (HRV) parameters, enables comparison between sinus rhythm (SR) and pre-AF periods. However, pre-AF rhythms remain unexplored using visibility graphs (VG). Therefore, the aim of this paper is to investigate the association of natural VG (NVG) features with the AF onset prediction.

Methods: The analysis was conducted on 5-minute RR interval segments of SR and pre-AF periods from the IRIDIA-AF database, incorporating classification based on standard HRV and NVG features, along with progression probability analysis. The classification analysis included different model configurations: HRV-only, NVG-only, and HRV + NVG combined features. The workflow incorporated standardization, removal of redundant features with correlation analysis, LASSO based feature selection, and classification using Gaussian Naïve Bayes.

Results: The results showed statistically significant improvement of area under the receiver operating characteristics curve (AUROC) for combined feature sets (AUROC = 0.74 [95% CI:0.55,0.81]) to single feature sets (HRV-only - AUROC = 0.58 [95% CI:0.45,0.71]; NVG-only - AUROC = 0.55 [95% CI:0.45,0.65]) on the separate test set (49 SR and 37 pre-AF segments). Shapley values were computed to interpret the model, indicating that standard HRV features have greater importance compared to NVG features. The probability progression analysis in the pre-AF period demonstrates the increase of probability approaching the AF onset however shows no visual difference between male and female patients.



Shapley values for model using combined HRV + NVG features.

Conclusion: These findings suggest that integrating NVG analysis with standard HRV parameters provides deeper insight into heart rate dynamics during the pre-AF period.