# Brugada Detection from 12-Lead ECG Using a Multi-Scale Hybrid Transformer with Explainability

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Brugada syndrome is associated with an increased risk of sudden cardiac death and requires accurate detection from 12-lead electrocardiograms (ECGs). Traditional approaches rely on rule-based criteria or handcrafted features, which may lack robustness and generalizability. This study aimed to develop an end-to-end deep learning model using raw ECG signals for Brugada detection and to provide interpretable insights using Grad-CAM visualizations.

We utilized the publicly available Brugada-HUCA database of 12-lead ECG recordings, cropping the original 12-second signals to 10-second segments for model input. An end-to-end Multi-Scale Hybrid Transformer (MS-Hybrid Transformer) model was developed to capture both local morphological features and long-range temporal dependencies across multiple leads. Data augmentation techniques such as scaling, baseline wander, Gaussian noise, and random point dropout were applied with randomization during training to improve generalization. Model performance was evaluated using 10-fold cross-validation with sensitivity, specificity, F1-score, area under the receiver operating characteristic curve (AUROC), and accuracy. To enhance interpretability, beat-averaged Grad-CAM was applied to generate representative visualizations highlighting salient regions contributing to model predictions.

The proposed MS-Hybrid Transformer demonstrated robust performance in detecting Brugada patterns from raw ECG inputs, achieving a sensitivity of 0.67, specificity of 0.92, F1-score of 0.66, AUROC of 0.87, and accuracy of 0.87. Grad-CAM visualizations highlighted clinically relevant regions, particularly in right precordial leads (V1–V2), corresponding to ST-segment elevation and characteristic Brugada morphology (red indicates higher importance, blue lower). Beat-averaged Grad-CAM enhanced interpretability by reducing noise and emphasizing stable diagnostic patterns across cardiac cycles.

An end-to-end MS-Hybrid Transformer model enables accurate and interpretable detection of Brugada syndrome from 12-lead ECGs. The integration of Grad-CAM provides clinically meaningful explanations aligned with established diagnostic criteria. This approach supports reliable automated screening and may assist clinicians in improving diagnostic confidence and workflow efficiency.

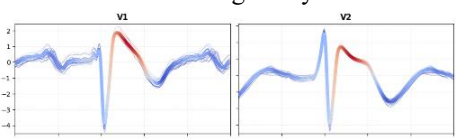


Figure 1. Beat-averaged Grad-CAM visualization for a representative Brugada case.