Graph Neural Networks for ECG-Based Risk Prediction in Brugada Syndrome

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Prognostic risk stratification in Brugada syndrome is challenging because clinically relevant electrocardiographic patterns can be intermittent, while available cohorts are small and heterogeneous across digital and digitized acquisitions.

We developed and evaluated a patient-level deep learning framework for Brugada prognosis on 137 patients (411 ECGs) that combines lead-wise morphology encoding, graph-based spatial modeling, and beat-level attention aggregation. Beat embeddings were extracted with a feed-forward encoder, processed with a graph neural network (GCN or GAT) using two predefined topologies (1) and (2), and aggregated with gated multiple-instance learning attention into a single ECG/patient representation. Training used stratified group 5-fold cross-validation at patient level, fold-specific lead-wise z-score normalization, and staged transfer learning from PTB-XL through intermediate adaptation tasks to final prognosis fine-tuning.

In the best prognosis configuration, cross-validated discrimination reached an AUC of 0.78. Because residual sensitivity/specificity imbalance remained, the metrics reported below refer to an optimized decision threshold. Across final variants, topology and message-passing choice substantially affected the operating point, with GCN(1) providing the best overall sensitivity/specificity trade-off and GAT(1) favoring sensitivity.

Model	B-Acc	Sens	Spec	AUC
FNN + GCN(1)	$\mathbf{0.771 \pm 0.066}$	$\mathbf{0.786 \pm 0.097}$	$\mathbf{0.756 \pm 0.163}$	$\mathbf{0.783 \pm 0.074}$
FNN + GAT(1)	0.740 ± 0.073	0.793 ± 0.070	0.687 ± 0.127	0.754 ± 0.079
FNN + GAT(2)	0.710 ± 0.036	0.691 ± 0.144	0.729 ± 0.169	0.733 ± 0.049
FNN + GCN(2)	0.650 ± 0.053	0.729 ± 0.197	0.572 ± 0.223	0.626 ± 0.095

A lead-aware graph model with gated attention pooling is a promising approach for Brugada prognosis in realistic heterogeneous ECG datasets. Lead-level explainability suggested a distributed inter-lead signature (notably aVR, V1, and inferior leads) rather than a single localized marker. Bias-aware preprocessing and patient-level validation are essential for reliable estimates, while external multi-center validation remains necessary for translation.