Quantitative Localization of Seizure Onset Zones Using Time–Frequency Neural Biomarkers

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Drug-resistant epilepsy affects nearly one-third of patients and often requires surgical intervention; however, success depends on accurate localization of the seizure onset zone (SOZ), currently identified through subjective interpretation of intracranial EEG with ~48% specificity. This study develops a quantitative classification framework using spectral entropy and frequency-domain features to improve SOZ localization and clinical decision-making. Intracranial EEG data from patients with Engel Class I surgical outcomes were analyzed to ensure accurate SOZ labeling. Signals were normalized and decomposed using Morlet wavelet transforms (4–60 Hz) to generate time–frequency representations. Spectral entropy, band power (theta, alpha, beta, gamma), and temporal modulation were extracted as features. Statistical analysis using the Wilcoxon rank-sum test revealed significant differences between SOZ and non-SOZ channels, with spectral entropy ($p = 0.000000005$), theta ($p = 0.0324$), beta ($p = 0.00152$), and gamma ($p = 0.0274$) demonstrating strong discriminative power, while alpha was not significant. Logistic regression and support vector machine (SVM) models were trained to classify SOZ versus non-SOZ channels. The model achieved specificity up to 86%, exceeding the clinical baseline. Notably, reduced agreement with clinical labels in surgical failure cases suggests improved identification of true epileptogenic regions and potential inaccuracies in existing annotations. This work introduces interpretable, computationally efficient biomarkers for seizure localization and establishes a scalable framework integrating signal processing and machine learning, increasing localization specificity to 86% and improving surgical precision while potentially reducing failed surgeries

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