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CORRELATION BETWEEN QUANTITATIVE EEG PARAMETERS AND MRI LESION VOLUME IN ACUTE ISCHEMIC STROKE

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Abstract. Acute ischemic stroke (AIS) remains a leading cause of disability and mortality worldwide. Early and accurate assessment of infarct burden is crucial for prognosis and therapeutic decision-making. Magnetic resonance imaging (MRI), particularly diffusion-weighted imaging (DWI), is the gold standard for lesion volume quantification, while quantitative electroencephalography (qEEG) provides real-time functional information about cerebral electrical activity. Recent evidence suggests that qEEG biomarkers strongly correlate with structural brain injury measured by MRI. This review-based analytical study aims to synthesize current evidence on the relationship between qEEG parameters and MRI lesion volume in AIS. Findings demonstrate that increased delta power, delta/alpha ratio (DAR), and theta activity correlate positively with infarct size, whereas alpha and beta activity show inverse relationships. These associations support qEEG as a non-invasive, rapid surrogate marker for lesion burden and stroke severity assessment.

Key words: Acute ischemic stroke, quantitative EEG, MRI lesion volume, delta power, neuroimaging correlation, stroke biomarkers.

Introduction. Acute ischemic stroke (AIS) is one of the most significant global health challenges, representing a leading cause of long-term disability and mortality worldwide. It occurs as a result of abrupt occlusion of cerebral arteries, leading to a rapid reduction in blood flow, oxygen deprivation, and subsequent neuronal injury. The extent of brain tissue damage depends on the duration and severity of ischemia, as well as the presence of collateral circulation. Clinically, AIS requires immediate diagnosis and intervention, as “time is brain” remains a fundamental principle in stroke management.

Magnetic resonance imaging (MRI), particularly diffusion-weighted imaging (DWI), is currently considered the gold standard for identifying ischemic lesions and quantifying infarct volume. DWI allows for early detection of cytotoxic edema within minutes of stroke onset, making it highly sensitive for acute infarction. However, despite its diagnostic accuracy, MRI has several limitations, including limited availability in emergency settings, high cost, contraindications in certain patients, and the inability to provide continuous monitoring of brain function.

In contrast, electroencephalography (EEG) offers a non-invasive, bedside, and real-time method of assessing cerebral electrical activity. Brain ischemia induces rapid electrophysiological changes due to energy failure, disruption of ion homeostasis, and synaptic dysfunction. These changes manifest as a suppression of fast-frequency rhythms (alpha and beta) and a relative increase in slow-wave activity (theta and delta). With advances in signal processing, quantitative EEG (qEEG) has emerged as a powerful tool that enables objective measurement and mathematical analysis of these frequency alterations, providing valuable biomarkers of cortical dysfunction.

Recent studies have demonstrated that qEEG parameters are not only sensitive to functional brain impairment but also show a significant relationship with structural damage observed on MRI. In particular, increased delta power, elevated theta activity, and higher delta/alpha ratio (DAR) have been consistently associated with larger infarct volumes. Conversely, preserved alpha and beta activity tends to correlate with smaller lesions and better neurological outcomes.

These findings suggest that qEEG may reflect the underlying pathophysiological severity of ischemic injury and could potentially serve as an indirect marker of lesion burden.

Despite growing evidence, the relationship between qEEG metrics and MRI-based lesion quantification remains an area of active investigation. There is still a need for systematic synthesis of existing findings to clarify the strength, consistency, and clinical relevance of this correlation. Understanding this relationship is particularly important for improving early stroke assessment, especially in prehospital or resource-limited environments where MRI access is delayed or unavailable. Therefore, this study aims to analyze and synthesize current scientific evidence regarding the correlation between quantitative EEG parameters and MRI lesion volume in acute ischemic stroke. By integrating neurophysiological and neuroimaging perspectives, the study seeks to highlight the potential role of qEEG as a rapid, cost-effective, and clinically useful tool in stroke evaluation and management.

Literature Review. The relationship between brain electrophysiological activity and structural damage in acute ischemic stroke (AIS) has been extensively explored over the past several decades. Advances in neuroimaging, particularly magnetic resonance imaging (MRI), together with developments in quantitative electroencephalography (qEEG), have enabled researchers to investigate how functional brain impairment corresponds to anatomical lesion characteristics. The integration of these two modalities has become an important focus in modern stroke neuroscience.

Early EEG Studies in Stroke. Initial investigations into EEG changes in stroke patients date back to the mid-20th century, when conventional EEG was used to detect generalized slowing of brain activity following cerebral infarction. These early studies consistently reported an increase in slow-wave activity, particularly delta (1–4 Hz) and theta (4–8 Hz) rhythms, in regions affected by ischemia. However, conventional EEG lacked quantitative precision and spatial resolution, limiting its clinical applicability in lesion characterization. Despite these limitations, early research established a fundamental principle: ischemic brain injury is associated with a shift from fast-frequency rhythms (alpha and beta) toward slow-wave dominance. This electrophysiological pattern became the foundation for later quantitative approaches.

Development of Quantitative EEG (qEEG). With the introduction of digital signal processing techniques, EEG analysis evolved into a more objective and reproducible method known as quantitative EEG. qEEG allows for spectral decomposition of EEG signals into measurable frequency bands and enables calculation of indices such as absolute and relative power, coherence, and asymmetry. Among these parameters, the delta/alpha ratio (DAR) and theta/alpha ratio have gained particular attention as robust indicators of cerebral dysfunction. Studies have shown that these ratios increase significantly in patients with acute stroke and correlate with neurological severity scales such as the National Institutes of Health Stroke Scale (NIHSS).

MRI-Based Stroke Imaging and Lesion Quantification. Magnetic resonance imaging, especially diffusion-weighted imaging (DWI), revolutionized stroke diagnostics by enabling early detection of ischemic lesions within minutes of onset. DWI lesion volume is widely used as a surrogate marker for infarct core, while perfusion imaging identifies potentially salvageable penumbral tissue. Quantitative MRI analysis has provided a standardized method for measuring infarct size in cubic centimeters (cm^3), allowing direct comparison with neurophysiological data. This has facilitated numerous studies investigating the correlation between structural brain damage and functional impairment.

Correlation Between qEEG and MRI Lesion Volume. A growing body of literature has demonstrated a significant relationship between qEEG parameters and MRI-defined lesion volume. Multiple clinical studies have reported that increased delta power is strongly associated with larger infarct sizes, while reduced alpha activity corresponds to more extensive cortical damage. For example, Finnigan et al. (2004) demonstrated that delta power measured in acute

stroke patients explained a substantial proportion of variance in lesion volume and clinical severity. Similarly, Sheorajpanday et al. (2011) reported that qEEG indices, particularly DAR, were significantly correlated with MRI lesion size and could predict functional outcomes. In addition, studies using continuous EEG monitoring have shown that changes in qEEG parameters over time reflect dynamic changes in cerebral perfusion and infarct progression. This suggests that qEEG may not only reflect static structural damage but also ongoing ischemic processes.

Frequency Band Alterations and Pathophysiological Significance. The observed EEG changes in stroke are closely linked to underlying neurophysiological mechanisms. Delta activity is believed to reflect cortical deafferentation and neuronal dysfunction in severely ischemic tissue. Theta activity may represent partial cortical impairment, while reduced alpha and beta activity indicate loss of normal thalamocortical connectivity. The delta/alpha ratio (DAR) has emerged as one of the most sensitive composite markers, integrating both pathological slow-wave increase and physiological fast-wave suppression. Higher DAR values are consistently associated with larger infarct volumes, greater neurological deficits, and poorer prognosis.

Comparison with Other Biomarkers. Compared to serum biomarkers such as S100B protein or neuron-specific enolase (NSE), qEEG provides real-time functional information without requiring laboratory processing. Unlike MRI, it allows continuous bedside monitoring, making it particularly useful in intensive care units and prehospital settings. However, MRI remains superior in anatomical resolution and precise lesion localization. Therefore, current research emphasizes multimodal approaches that combine qEEG and MRI to improve diagnostic accuracy and prognostic modeling.

Current Gaps in Literature. Despite promising findings, several limitations remain in existing studies. Many investigations involve small sample sizes and heterogeneous patient populations. Differences in EEG acquisition protocols, electrode montages, and signal processing methods also limit comparability across studies. Furthermore, confounding factors such as sedation, comorbid neurological conditions, and medication effects are not always adequately controlled. Another important gap is the lack of standardized thresholds for qEEG parameters that could be used clinically to estimate infarct volume. Most studies report correlation coefficients rather than predictive models applicable in routine practice. Overall, the literature strongly supports a meaningful correlation between quantitative EEG parameters and MRI lesion volume in acute ischemic stroke. Increased slow-wave activity, particularly delta power and delta/alpha ratio, consistently correlates with larger infarct size, while higher-frequency rhythms show inverse relationships. Although MRI remains the gold standard for structural assessment, qEEG represents a valuable complementary tool for functional evaluation and early stroke severity estimation. Future research is needed to standardize qEEG methodologies and develop integrated neuroimaging–neurophysiology models for improved clinical decision-making.

Discussion. The present study synthesizes evidence regarding the relationship between quantitative electroencephalography (qEEG) parameters and magnetic resonance imaging (MRI)-based lesion volume in acute ischemic stroke (AIS). The findings from the reviewed literature consistently demonstrate a robust association between electrophysiological disturbances and structural brain damage, highlighting the potential of qEEG as a functional surrogate marker for infarct burden.

Neurophysiological Interpretation of qEEG–MRI Correlation. One of the most consistent observations across studies is the strong positive correlation between slow-wave activity—particularly delta (1–4 Hz) power—and MRI-defined lesion volume. This relationship can be explained by the underlying pathophysiology of cerebral ischemia. In acute stroke, energy failure due to reduced cerebral blood flow leads to disruption of ATP-dependent ion pumps, membrane depolarization, and synaptic failure. These processes result in neuronal dysfunction and cortical

deafferentation, which manifest as increased delta activity on EEG. Similarly, theta activity (4–8 Hz) is associated with moderate cortical impairment and partial preservation of neuronal networks, while alpha (8–13 Hz) and beta (13–30 Hz) rhythms reflect intact thalamocortical connectivity and normal cognitive processing. The progressive reduction of alpha and beta activity with increasing infarct volume indicates loss of functional cortical integrity. Among all qEEG parameters, the delta/alpha ratio (DAR) emerges as the most reliable composite biomarker. DAR integrates both pathological increase in slow-wave activity and suppression of physiological fast rhythms, providing a sensitive index of cerebral dysfunction. Its strong correlation with MRI lesion volume across multiple studies suggests that it may serve as a simplified, clinically applicable marker of stroke severity.

Structural–Functional Coupling in Acute Ischemic Stroke. The observed correlation between qEEG and MRI findings reflects a fundamental principle of neurovascular coupling: structural damage in brain tissue is directly associated with disruption of electrical activity. MRI provides high-resolution anatomical visualization of infarcted tissue, particularly through diffusion-weighted imaging (DWI), which detects cytotoxic edema within minutes of ischemia onset. However, MRI captures structural changes, whereas qEEG reflects dynamic functional impairment. The strong correlation between these modalities suggests that electrophysiological alterations occur in parallel with structural injury progression. Importantly, qEEG may detect functional abnormalities in the ischemic penumbra—regions that are still viable but electrically suppressed—before irreversible structural damage becomes visible on imaging.

Clinical Significance of qEEG as a Surrogate Biomarker. The clinical implications of the qEEG–MRI correlation are highly significant. MRI, although considered the gold standard for stroke imaging, is not always immediately accessible in emergency or resource-limited settings. In contrast, qEEG can be performed at the bedside, is non-invasive, and allows continuous monitoring of cerebral function. The ability of qEEG parameters, particularly delta power and DAR, to estimate lesion volume provides a valuable tool for early stroke assessment. This is especially relevant in the hyperacute phase, where rapid decision-making regarding thrombolysis or mechanical thrombectomy is critical. In addition, qEEG may assist in monitoring treatment response and detecting secondary neurological deterioration.

Comparison with Existing Neuroimaging and Biomarkers. When compared to MRI, qEEG does not provide anatomical localization or precise volumetric measurement; however, it offers superior temporal resolution and functional sensitivity. Compared to serum biomarkers such as S100B or neuron-specific enolase (NSE), qEEG has the advantage of providing real-time brain activity data without laboratory delay. The integration of qEEG with MRI and clinical scales (e.g., NIHSS, mRS) represents a multimodal approach that may significantly improve stroke stratification and prognostication. Some studies suggest that combined models incorporating qEEG and imaging data achieve higher predictive accuracy for functional outcomes than either modality alone.

Variability and Methodological Considerations. Despite strong overall evidence, variability exists across studies due to differences in EEG acquisition protocols, electrode configurations, filtering techniques, and timing of recordings relative to stroke onset. Sedation, metabolic disturbances, and pre-existing neurological conditions may also influence EEG patterns and introduce confounding effects. MRI-based lesion quantification is also subject to methodological differences, including variability in segmentation techniques and thresholding methods for infarct delineation. These inconsistencies limit direct comparison between studies and highlight the need for standardized protocols in both EEG and neuroimaging research.

Pathophysiological Significance of Temporal Dynamics. An important aspect of qEEG analysis is its ability to capture dynamic changes over time. Several studies have demonstrated that EEG abnormalities evolve in parallel with infarct progression or recovery. Increasing delta activity and rising DAR values may indicate worsening ischemia, whereas partial restoration of

alpha activity may reflect reperfusion and neuronal recovery. This temporal sensitivity gives qEEG a unique advantage over static imaging techniques, allowing continuous assessment of cerebral function in critically ill patients.

Limitations of Current Evidence. Although the correlation between qEEG and MRI lesion volume is well established, several limitations must be acknowledged. Most studies are observational and involve relatively small sample sizes. There is also heterogeneity in patient populations, stroke subtypes, and time intervals between symptom onset and data acquisition. Furthermore, there is a lack of universally accepted thresholds for qEEG parameters that can reliably predict specific lesion volumes or clinical outcomes. This limits the immediate translation of research findings into routine clinical practice.

Future Directions. Future research should focus on the development of standardized qEEG acquisition and analysis protocols to improve reproducibility across studies. Large-scale multicenter trials are needed to validate qEEG-based predictive models for lesion volume estimation and functional outcomes. Emerging technologies such as artificial intelligence and machine learning offer promising opportunities for integrating qEEG with MRI and clinical data to create predictive algorithms for personalized stroke management. Additionally, portable EEG devices may facilitate prehospital stroke assessment and early triage, potentially improving treatment timelines and outcomes. Overall, the evidence strongly supports a meaningful and clinically relevant correlation between quantitative EEG parameters and MRI lesion volume in acute ischemic stroke. qEEG, particularly delta power and delta/alpha ratio, reflects the extent of structural brain damage and provides valuable functional information that complements MRI findings. While MRI remains the gold standard for anatomical assessment, qEEG represents a promising, rapid, and accessible tool for functional evaluation, early diagnosis, and continuous monitoring of stroke patients.

Conclusion. This study analyzed and synthesized existing scientific evidence regarding the correlation between quantitative electroencephalography (qEEG) parameters and magnetic resonance imaging (MRI) lesion volume in acute ischemic stroke (AIS). The reviewed literature consistently demonstrates a strong and clinically meaningful relationship between electrophysiological alterations and structural brain damage. In particular, increased slow-wave activity—especially delta power—and elevated delta/alpha ratio (DAR) show a strong positive correlation with MRI-defined infarct volume. These parameters reflect severe cortical dysfunction, neuronal deafferentation, and metabolic failure in ischemic brain tissue. Conversely, preservation of alpha and beta activity is associated with smaller lesion size and better neurological outcomes, indicating maintained cortical integrity. MRI, particularly diffusion-weighted imaging (DWI), remains the gold standard for accurate anatomical assessment of ischemic lesions. However, its limitations in terms of accessibility, cost, and real-time monitoring highlight the importance of complementary diagnostic tools. qEEG provides a rapid, non-invasive, and bedside method for evaluating functional brain impairment, making it particularly valuable in the hyperacute phase of stroke. The integration of qEEG and MRI offers a multimodal approach that enhances both structural and functional assessment of cerebral ischemia. This combined strategy has the potential to improve early diagnosis, guide therapeutic decisions, and refine prognostic evaluation in patients with AIS. Despite promising findings, heterogeneity in study designs, EEG methodologies, and imaging protocols limits full standardization. Therefore, future research should focus on large-scale prospective studies, development of unified qEEG biomarkers, and integration of artificial intelligence-based predictive models to improve clinical applicability. Overall, qEEG represents a promising adjunct tool to MRI, with significant potential in advancing stroke diagnostics and improving patient outcomes.

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