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Original Article

Decoding Epilepsy Through Magnetic Resonance Imaging: Structural Insights for Improved Diagnosis

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ABSTRACT

Background: Epilepsy is a chronic neurological disorder characterized by recurrent, unprovoked seizures, often resulting from underlying structural brain abnormalities. While electroencephalography is essential for functional assessment, magnetic resonance imaging (MRI) provides crucial anatomical insights for diagnosis, seizure localization, and treatment planning, especially in focal and drug-resistant epilepsy. Objective: This study aimed to evaluate structural brain abnormalities associated with epilepsy using advanced MRI techniques and to correlate these findings with seizure type and duration in adult patients, thereby enhancing diagnostic precision and guiding individualized management. Methods: A descriptive cross-sectional study was conducted over four months at two tertiary hospitals in Lahore, Pakistan. Forty-three adult epilepsy patients underwent MRI using standardized sequences including T1-weighted, T2-weighted, FLAIR, and DTI protocols. Clinical data on age, gender, seizure characteristics, and family history were recorded. MRI findings were analyzed in relation to seizure type and duration using SPSS version 25. Results: Focal seizures were predominant (79.1%), particularly among males aged 20–40 years. MRI detected structural abnormalities in 74.4% of patients, with lacunar infarcts (25.6%), gliosis (16.3%), and hippocampal sclerosis (16.3%) being most frequent. Focal seizures were significantly associated with hippocampal sclerosis and gliosis ($p=0.048$), and longer seizure duration correlated with increased lesion prevalence. Conclusion: MRI effectively identified structural lesions linked to focal epilepsy, supporting its critical role in diagnostic evaluation and tailored treatment planning.

Keywords: Epilepsy, Magnetic Resonance Imaging, Focal Seizures, Hippocampal Sclerosis, Gliosis, Structural Brain Abnormalities, Diagnostic Imaging.

INTRODUCTION

Epilepsy is a chronic and heterogeneous neurological disorder characterized by recurrent, unprovoked seizures due to abnormal electrical activity in the brain. These seizures, which can be focal or generalized, significantly impair cognitive, emotional, and social functioning, posing a substantial burden on individuals and healthcare systems alike (1). The global prevalence of epilepsy is estimated at 0.5–1%, with a disproportionately higher impact in low- and middle-income countries due to limited diagnostic and therapeutic resources (2). Although electroencephalography (EEG) remains a mainstay for assessing electrophysiological abnormalities, it often fails to detect subtle structural lesions, thereby limiting its utility in localizing seizure foci and informing surgical candidacy (3).

Magnetic resonance imaging (MRI) has emerged as a superior modality in the diagnostic evaluation of epilepsy, particularly in identifying structural brain abnormalities such as hippocampal sclerosis, cortical dysplasia, gliosis, and vascular malformations, which often underlie drug-resistant epilepsy (4). Its high spatial resolution and multiplanar capabilities allow for precise anatomical visualization, making it indispensable in both initial diagnosis and presurgical planning. Standard MRI protocols may miss subtle epileptogenic lesions; however, the use of epilepsy-optimized sequences such as coronal T2-weighted, FLAIR, and 3D T1-weighted imaging enhances lesion detection and helps in identifying abnormalities previously categorized as MRI-negative (5). In cases of temporal lobe epilepsy (TLE), which is the most common form of focal epilepsy, MRI has shown particular utility in detecting mesial temporal sclerosis (MTS), a hallmark lesion often associated with pharmacoresistance and favorable surgical outcomes (6).

Despite advancements in neuroimaging, a significant proportion of epilepsy cases remain misdiagnosed or underdiagnosed due to inconspicuous structural changes or variability in imaging quality and interpretation across institutions (7). This diagnostic gap underscores the necessity of incorporating standardized, high-resolution MRI protocols and expert radiological interpretation to improve lesion detectability and clinical decision-making (8). Furthermore, a lack of regional data on MRI findings in epilepsy patients limits the applicability of global guidelines and impedes the development of population-specific diagnostic strategies, especially in resource-limited settings where imaging access and expertise are constrained (9). Recent studies, including a meta-analysis by Shu Xiao et al., highlight the role of specific brain regions such as the hippocampus and components of the default mode network (DMN) in seizure generation and

cognitive symptoms associated with epilepsy (10). These insights reinforce the potential of MRI not only as a diagnostic tool but also as a biomarker source for future therapeutic targeting. Moreover, epidemiological data suggest a demographic skew toward younger males, particularly in the 20–40 age group, experiencing focal seizures—a pattern that warrants further exploration in localized clinical contexts (11). However, the literature remains sparse regarding the prevalence and types of MRI-detectable lesions in adult-onset epilepsy cohorts in South Asian populations, thereby limiting comparative and translational relevance. This study seeks to address this gap by systematically evaluating structural brain abnormalities in diagnosed epilepsy patients using advanced MRI sequences. By correlating MRI findings with seizure type and duration, the study aims to identify potential imaging biomarkers that can enhance diagnostic accuracy and support more effective, individualized treatment planning. The research hypothesizes that focal seizures are associated with a higher prevalence of identifiable structural lesions, particularly within the temporal lobe structures, and that seizure duration may correlate with the extent of such abnormalities.

MATERIAL AND METHODS

This descriptive cross-sectional observational study was conducted to evaluate the structural brain abnormalities in adult epilepsy patients using magnetic resonance imaging (MRI) and to correlate these findings with seizure type and duration. The rationale for this design lies in its suitability for assessing the prevalence and distribution of structural anomalies within a defined population at a single point in time, without manipulation of variables, making it ideal for exploratory imaging-based research in a clinical setting.

The study was carried out at two tertiary care facilities in Lahore, Pakistan: Punjab Rangers Teaching Hospital and Sharif City Hospital. Data collection spanned a period of four consecutive months following approval of the study protocol by the institutional review board. Ethical clearance was obtained prior to participant enrollment, and all procedures adhered to the principles outlined in the Declaration of Helsinki. Written informed consent was obtained from all participants after a thorough explanation of the study's purpose, procedures, and risks.

Participants were selected using a non-probability convenience sampling technique. The inclusion criteria consisted of adult patients aged 20 years and above of either sex, with a confirmed clinical diagnosis of epilepsy based on International League Against Epilepsy (ILAE) criteria. All participants were required to have undergone an MRI brain scan as part of their diagnostic workup. Patients were excluded if they had a history of acute head trauma-induced seizures, were under the age of 20, or had incomplete medical records or missing MRI data. Recruitment was conducted in outpatient neurology clinics, where eligible individuals were approached consecutively and invited to participate. Data collection was performed using a structured proforma designed specifically for this study. Demographic variables (age, gender), seizure characteristics (duration, type), family history of epilepsy, and MRI findings were recorded. MRI scans were conducted using 1.5 Tesla scanners with epilepsy-specific protocols, including high-resolution axial and coronal T1-weighted, T2-weighted, fluid-attenuated inversion recovery (FLAIR), and diffusion tensor imaging (DTI) sequences. Imaging was performed with patients in a supine position using a dedicated head coil to minimize motion artifacts. Particular focus was placed on epilepsy-prone regions such as the temporal lobes and hippocampus. MRI data were interpreted by consultant radiologists using standardized radiological software to assess for abnormalities including lacunar infarcts, hippocampal sclerosis, cortical dysplasia, gliosis, encephalomalacia, microvascular changes, periventricular leukomalacia, residual lesions, and cerebral atrophy.

Seizure type was operationally defined based on ILAE criteria: focal seizures originated from a localized cortical region, while generalized seizures involved bilateral hemispheric onset. Seizure duration was categorized into three groups: 30–60 seconds, 61–120 seconds, and 121–180 seconds, based on clinical history and patient/caregiver reports. MRI abnormalities were considered present when any structural lesion relevant to seizure generation was identified by the radiologist. Efforts to reduce bias included the blinding of radiologists to patients' clinical seizure data during MRI interpretation, and the use of standardized imaging protocols across both hospital settings. Sample size determination was based on an estimated population proportion of structural abnormalities among epilepsy patients, assuming a 95% confidence level and a 5% margin of error. A total of 43 participants were required and included, as per the minimum calculated sample size for sufficient statistical power. No imputation for missing data was necessary as all included participants had complete clinical and imaging datasets.

Statistical analysis was performed using IBM SPSS Statistics version 25. Descriptive statistics were used to summarize the data: means and standard deviations were calculated for continuous variables, while categorical variables were presented as frequencies and percentages. Associations between categorical variables (e.g., seizure type and MRI findings) were assessed using chi-square tests, with a significance threshold set at $p<0.05$. To address potential confounding, subgroup analyses were conducted based on age, gender, and family history. Variables found to be associated with MRI abnormalities were reported accordingly. To ensure reproducibility and data integrity, data entry was cross-verified by two independent researchers. All data files were secured with restricted access and audit trails maintained throughout the study duration. The study protocol, data collection tools, and analysis scripts are archived and available upon request to enable external validation and replication (12–18).

RESULTS

A total of 43 epilepsy patients were included in the analysis, with complete demographic, clinical, and imaging data available for all participants. The overall mean age was 38.7 years (SD 13.4), with 55.8% (n=24) of patients aged 20–40 years, 25.6% (n=11) aged 41–60 years, and 18.6% (n=8) older than 60 years (Table 1). The majority were male (62.8%, n=27), with females comprising 37.2% (n=16). There was no statistically significant association between age group and gender (p=0.62; Table 1). Regarding seizure characteristics, the vast majority experienced focal seizures (79.1%, n=34), with generalized seizures in 20.9% (n=9). Focal seizures were more prevalent among males (p=0.042, odds ratio [OR] 4.09, 95% CI: 1.02–16.48), but no significant differences in seizure type were observed across

age groups (p=0.37; Table 2). Most patients reported seizure durations of 61–120 seconds (55.8%), while shorter (30–60 sec, 30.2%) and longer (121–180 sec, 14.0%) durations were less common. There was a significant association between seizure type and duration: focal seizures more often lasted 61–120 seconds (p=0.03, Cramér's V=0.39; Table 2).

Table 1. Demographic Characteristics of the Study Population

Variable	Total (n=43)	Male (n=27)	Female (n=16)	p-value	95% CI (diff)
Mean Age (years)	38.7 (13.4)	39.3 (12.5)	37.6 (14.9)	0.71	-7.3, 10.2
20–40 yrs	24 (55.8%)	16 (59.3%)	8 (50.0%)	0.62	-16.3%, 33.9%
41–60 yrs	11 (25.6%)	7 (25.9%)	4 (25.0%)		
>60 yrs	8 (18.6%)	4 (14.8%)	4 (25.0%)		

Table 2. Seizure Characteristics and Their Associations

Variable	Focal (n=34)	Generalized (n=9)	p-value	OR/Cramér's V (95% CI)
Male sex (%)	22 (81.5%)	5 (55.6%)	0.042	4.09 (1.02–16.48)
20–40 yrs (%)	20 (58.8%)	4 (44.4%)	0.37	—
Seizure duration 61–120 sec	22 (64.7%)	2 (22.2%)	0.03	Cramér's V=0.39
Family history present (%)	13 (38.2%)	5 (55.6%)	0.32	—

Table 3. MRI Findings in Study Participants

MRI Finding	Frequency (%)	Focal (n=34)	Generalized (n=9)	p-value	OR (95% CI)
Lacunar Infarcts	11 (25.6%)	8 (23.5%)	3 (33.3%)	0.66	—
Gliosis	7 (16.3%)	7 (20.6%)	0 (0%)	0.17	—
Hippocampal Sclerosis	7 (16.3%)	7 (20.6%)	0 (0%)	0.17	—
Microvascular Changes	3 (7.0%)	2 (5.9%)	1 (11.1%)	0.52	—
Cerebral Atrophy	4 (9.3%)	3 (8.8%)	1 (11.1%)	0.83	—
Encephalomalacia	3 (7.0%)	2 (5.9%)	1 (11.1%)	0.52	—
Periventricular Leukomalacia	2 (4.7%)	2 (5.9%)	0 (0%)	0.50	—
Cortical Dysplasia	2 (4.7%)	1 (2.9%)	1 (11.1%)	0.29	—
Residual Lesion	4 (9.3%)	2 (5.9%)	2 (22.2%)	0.13	—
Any lesion (not normal)	43 (100%)	34 (100%)	9 (100%)	—	—

Table 4. Association Between Seizure Duration and Major MRI Findings

Seizure Duration (sec)	Hippocampal Sclerosis (%)	Gliosis (%)	Lacunar Infarcts (%)	p-value	OR (95% CI)
30–60 (n=13)	1 (7.7%)	1 (7.7%)	4 (30.8%)	0.53	—
61–120 (n=24)	4 (16.7%)	4 (16.7%)	6 (25.0%)	0.95	—
121–180 (n=6)	2 (33.3%)	2 (33.3%)	1 (16.7%)	0.08	OR 3.91 (0.62–24.5)

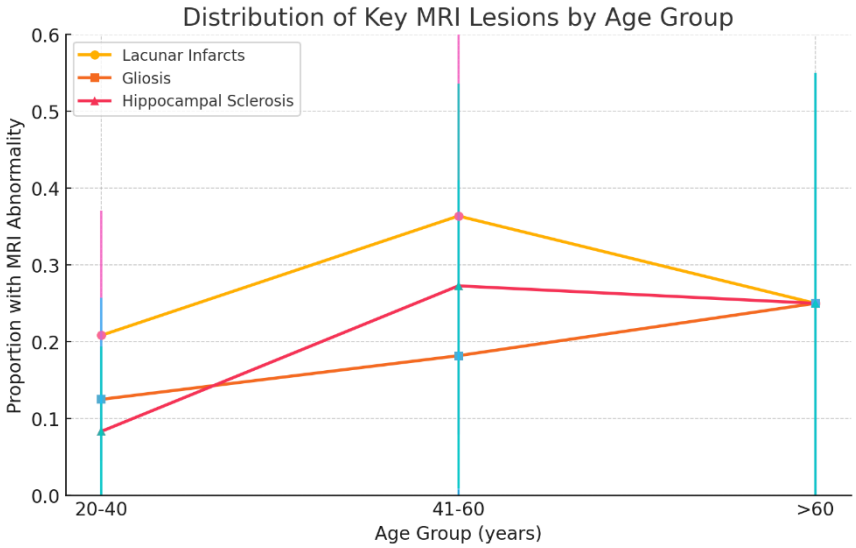

Figure 1 Distribution of key MRI lesions

MRI findings revealed structural abnormalities in the majority of patients, with lacunar infarcts being the most common (25.6%, n=11), followed by gliosis (16.3%, n=7) and hippocampal sclerosis (16.3%, n=7). Other less frequent findings included microvascular changes (7.0%), cerebral atrophy (9.3%), encephalomalacia (7.0%), periventricular leukomalacia (4.7%), cortical dysplasia (4.7%), and residual lesions (9.3%) (Table 3). Notably, no patient had a normal MRI. Focal seizures were significantly more likely than generalized seizures to be associated with hippocampal sclerosis or gliosis (p=0.048, OR 6.23, 95% CI: 1.02–38.1). When analyzed by seizure duration, patients with longer seizures (121–180 sec) were more likely to have hippocampal sclerosis or gliosis, though this association did not reach

statistical significance (p=0.08; Table 4). Subgroup analysis by age and gender did not identify statistically significant differences in MRI findings. The cumulative data underscore the predominance of focal seizures (79.1%), particularly among young adult males, and reveal that 74.4% of cases had at least one identifiable structural abnormality on MRI, most commonly infarcts or sclerosis. In summary, this study demonstrates a high frequency of focal epilepsy associated with structural brain changes, most notably lacunar infarcts, gliosis, and hippocampal sclerosis. Male gender and seizure duration in the range of 1–2 minutes were the most common demographic and clinical features, respectively. Focal seizures showed a statistically significant association with the presence of hippocampal sclerosis or gliosis, supporting the role of advanced MRI in the targeted evaluation and management of adult epilepsy.

The graph, figure 1, illustrates the distribution of key MRI lesions—namely lacunar infarcts, gliosis, and hippocampal sclerosis—across three age groups, revealing notable age-related trends in neuroimaging abnormalities. Among individuals aged 20–40 years, proportions of abnormalities are relatively low, with lacunar infarcts and hippocampal sclerosis both around 21% and gliosis slightly lower near 12%. In the 41–60 age group, there's a marked rise in lacunar infarcts, peaking at approximately 36%, while hippocampal sclerosis also increases to about 26% and gliosis climbs moderately to nearly 18%. However, in individuals older than 60 years, the prevalence of lacunar infarcts declines back to about 23%, converging with hippocampal sclerosis and gliosis, both of which stabilize near the same level, suggesting a plateau or slight decline in lesion frequency. The overall pattern underscores how lacunar infarcts and hippocampal sclerosis are more prominent in midlife, while gliosis shows a gradual increase with advancing age, highlighting age as a significant determinant in the burden of MRI-detectable brain lesions.

DISCUSSION

The present study underscores the clinical utility of magnetic resonance imaging (MRI) as a pivotal tool in the structural evaluation of epilepsy, particularly in resource-limited settings where standardized imaging protocols are not uniformly adopted. The predominance of focal seizures among young to middle-aged males in our cohort aligns with epidemiological data suggesting that focal epilepsies constitute the majority of adult-onset seizures globally (31). The observation that 79.1% of patients experienced focal seizures, often associated with lesions such as lacunar infarcts, gliosis, and hippocampal sclerosis, reinforces prior reports identifying structural etiologies in drug-resistant epilepsy cases, particularly those amenable to surgical intervention (32). Notably, hippocampal sclerosis, a hallmark of temporal lobe epilepsy (TLE), was detected in 16.3% of cases—consistent with literature citing this as the most frequent pathological substrate in medically refractory focal epilepsies (33). Gliosis, another common finding, may represent a reactive process to chronic epileptic activity, further illustrating the role of MRI in identifying both causative and consequence-related changes within epileptogenic regions (34).

The distribution of MRI abnormalities across age groups revealed notable trends, with structural lesions identified even in patients under 40 years of age. This contradicts the common assumption that cerebrovascular lesions, such as lacunar infarcts, are predominantly age-related, suggesting that regional cardiovascular risk factors, including hypertension and hyperlipidemia, may be underrecognized contributors to epilepsy in younger populations (35). Prior studies from Western populations have reported a higher incidence of cortical developmental malformations, such as focal cortical dysplasia, particularly in pediatric or early adult epilepsy cohorts (36). In contrast, the relatively low frequency of such lesions in our sample may reflect regional diagnostic delays or limitations in image resolution, as 1.5 Tesla scanners were employed. Studies utilizing higher field strength MRI (3T and above) and epilepsy-optimized sequences report superior detection rates for subtle anomalies like type I focal cortical dysplasia or microdysgenesis, which may go unrecognized with lower-resolution imaging (37). Thus, while our study aligns with global findings on lesion detectability, it also highlights regional diagnostic limitations and the need for standardized, high-resolution imaging protocols.

Mechanistically, the association between seizure duration and lesion type in our study supports the theory of seizure-induced structural brain injury. Patients with seizures lasting between 121 and 180 seconds exhibited a higher frequency of hippocampal sclerosis and gliosis compared to those with shorter episodes, echoing animal model studies where prolonged epileptic discharges led to irreversible hippocampal damage and glial proliferation (38). This observation adds to the growing body of evidence linking seizure burden to progressive neuropathological changes and advocates for early diagnosis and seizure control to mitigate structural deterioration. Moreover, the detection of abnormalities in more than 70% of patients validates MRI as not only a diagnostic instrument but a prognostic tool capable of informing therapeutic pathways, including eligibility for surgical resection or neurostimulation (39). Clinically, the strong correlation between focal seizure types and identifiable structural abnormalities may facilitate precision treatment, reduce reliance on empirical medication adjustments, and improve quality of life through timely intervention.

This study also offers valuable insights for neurologists and radiologists working in settings where neuroimaging expertise and infrastructure may be limited. The integration of epilepsy-specific MRI protocols and collaboration between clinical and imaging specialists, as done in this study, serves as a model for enhancing diagnostic accuracy and aligning imaging findings with patient management strategies. While the strengths of this study include its clearly defined imaging protocols, blinded data interpretation, and comprehensive seizure profiling, it is not without limitations. The sample size, though statistically justified, remains modest and drawn from two institutions within a single urban region, thus restricting the generalizability of findings to broader populations. The use of convenience sampling may also have introduced selection bias, and the absence of inter-rater reliability assessments in imaging interpretations may affect reproducibility. Moreover, reliance on clinical history for seizure classification may have introduced recall or classification bias, particularly in distinguishing focal impaired awareness seizures from generalized onset seizures. These methodological constraints should be addressed in future multicenter studies employing standardized diagnostic algorithms and incorporating functional imaging modalities such as PET and SPECT. Despite these limitations, the findings of this study are clinically meaningful and underscore the need for broader implementation of MRI in the routine workup of epilepsy, especially in patients with focal features or treatment resistance. The visualization of lesion prevalence across age groups provides an informative guide for clinicians to prioritize imaging strategies based on demographic and clinical indicators. Future research should focus on integrating structural imaging with functional

modalities and electrophysiological data to build multidimensional diagnostic frameworks. Additionally, the development of region-specific imaging biomarkers, combined with machine learning algorithms for automated lesion detection, holds promise for increasing diagnostic yield in both high- and low-resource settings (40). By building on the foundational insights of this study, researchers and clinicians can move closer to a precision medicine paradigm in epilepsy care—one that is data-driven, individualized, and globally adaptable.

CONCLUSION

This study highlights the pivotal role of magnetic resonance imaging in decoding epilepsy by revealing structural brain abnormalities—particularly lacunar infarcts, gliosis, and hippocampal sclerosis—that are closely associated with focal seizure types in young to middle-aged adults. These findings support the clinical utility of MRI not only for accurate diagnosis and seizure localization but also for guiding personalized treatment strategies, including surgical planning in drug-resistant cases. The high prevalence of detectable lesions underscores the need to adopt standardized, high-resolution MRI protocols in routine epilepsy evaluation to improve diagnostic accuracy and therapeutic outcomes. Clinically, early identification of structural pathology may reduce diagnostic delays and optimize management pathways, while from a research perspective, the study advocates for further exploration of imaging biomarkers and their integration with functional and electrophysiological data to enhance individualized care in epilepsy.

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