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Comparative Efficacy of Neuroimaging Modalities in Diagnosing Structural Abnormalities and Influencing Surgical Outcomes in Newly Diagnosed Epilepsy

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A B S T R A C T

Introduction/Background: This study aimed to compare the efficacy of traditional and advanced neuroimaging modalities in diagnosing structural abnormalities, influencing treatment decisions, and surgical outcomes in patients with newly diagnosed epilepsy

Methods: *A prospective observational study was conducted on 150 patients at Batra Hospital and Medical Research Centre, New Delhi, from January 2023 to July 2024. Participants were divided into two groups: the Traditional Imaging Group (Computed Tomography [CT]) and the Advanced Imaging Group (Magnetic Resonance Imaging [MRI], Positron Emission Tomography [PET], and Single Photon Emission Computed Tomography [SPECT]). Primary outcomes included diagnostic accuracy, impact on treatment decisions, and seizure-free status at a 12-month follow-up. Data were analyzed using SPSS, and comparative analyses were performed.*

Results: *The Advanced Imaging Group exhibited a significantly higher detection rate for structural abnormalities (68%) than the Traditional Imaging Group (32%). Advanced imaging findings influenced treatment decisions in 45% of the cases compared to 20% in the Traditional Imaging Group. Surgical intervention was more frequently recommended in the Advanced Imaging Group (22% vs. 8%, respectively). At the 12-month follow-up, 68% of the patients in the Advanced Imaging Group were seizure-free compared to 52% in the Traditional Imaging Group.*

Conclusions: *The integration of advanced neuroimaging techniques, including MRI, PET, and SPECT, significantly improves diagnostic accuracy and influences treatment decisions, leading to better surgical outcomes and higher seizure-free rates in patients with epilepsy. These findings advocate the routine use of advanced neuroimaging in epilepsy management to optimize patient care.*

Keywords:*Neuroimaging, Epilepsy, MRI, PET, SPECT, Diagnostic Accuracy, Treatment Decisions, Surgical Outcomes,*

INTRODUCTION

Epilepsy is a prevalent chronic neurological disorder characterized by recurrent, unprovoked seizures that affects over 50 million people worldwide [1]. Despite advances in medical therapies, approximately one-third of patients with epilepsy continue to experience seizures despite optimal pharmacological treatment, underscoring the importance of accurate diagnosis and individualized management strategies [2,3]. The International League Against Epilepsy (ILAE) has emphasized the need for precise diagnostic criteria and the identification of structural abnormalities to guide treatment decisions [4].

Neuroimaging has become a cornerstone of the diagnostic process of epilepsy with advancements in imaging techniques that significantly improve the identification of epileptogenic lesions. Traditional imaging modalities, such as computed tomography (CT), have been widely used for the initial assessment, primarily because of their accessibility and ability to detect gross structural anomalies. However, the sensitivity of CT is limited, particularly for detecting subtle cortical abnormalities that are often implicated in epilepsy [5].

The advent of Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET), and single-photon emission computed tomography (SPECT) has revolutionized the diagnosis of epilepsy, offering higher sensitivity and specificity in detecting structural and functional brain abnormalities [6,7]. MRI, with its superior soft tissue contrast, is particularly effective in identifying lesions such as mesial temporal sclerosis (MTS) and cortical dysplasia, which are common in patients with drug-resistant epilepsy [8]. PET and SPECT further complement MRI by providing metabolic and perfusion data, which are critical in cases where structural imaging alone is inconclusive [9,10]

Despite these advancements, integration of these advanced imaging techniques into routine clinical practice remains inconsistent, particularly in resource-limited settings. This study aimed to evaluate the effect of advanced neuroimaging techniques on the diagnosis and management of patients with newly diagnosed epilepsy. We hypothesized that the use of MRI, PET, and SPECT would lead to improved diagnostic accuracy, better informed treatment decisions, and enhanced patient outcomes compared to traditional imaging methods.

MATERIAL & METHODS

Patient Cohort: This study was designed as a prospective observational study conducted at the Department of Neurology, Batra Hospital & Medical Research Centre, New Delhi, between January 2023 and July 2024. The primary objective of this study was to evaluate the effect of advanced neuroimaging techniques on the diagnosis and management of newly diagnosed epilepsy. The study adhered to the ethical guidelines set forth by the Declaration of Helsinki and was approved by the Institutional Review Board (IRB) of Batra Hospital and Medical Research Centre (IRB No: 2022-NEP-001)

Methodology: A total of 180 patients were initially screened for eligibility, of whom 150 met the inclusion criteria and were enrolled in the study. Participants were then divided into two groups based on the imaging modality used: the Traditional Imaging Group (CT) and the Advanced Imaging Group (MRI, PET, and SPECT).

Other methods: Clinical data were collected at baseline using detailed medical histories, neurological examinations, and standardized seizure questionnaires. The information gathered included patient demographics, seizure type and frequency, epilepsy duration, and any relevant family history of neurological disorders.

Imaging Protocols

The participants underwent neuroimaging as part of their diagnostic workups. Imaging protocols were standardized to ensure consistency across the study population.

- CT Scan (Traditional Imaging Group): Performed using a 64-slice scanner (Siemens SOMATOM Definition), focusing on identifying gross structural abnormalities such as tumors, significant atrophy, or hemorrhages. Images were acquired in the axial, coronal, and sagittal planes with 5-mm slice thickness.

- MRI (Advanced Imaging Group): Conducted on a 3-Tesla MRI scanner (Philips Achieva) using an epilepsy-specific protocol. The sequences included T1-weighted, T2-weighted, FLAIR, and diffusion-weighted imaging. High-resolution 3D volumetric images were also obtained to assess subtle structural abnormalities such as hippocampal sclerosis or cortical dysplasia.

- Positron emission tomography (PET Advanced Imaging Group) Fluorodeoxyglucose (FDG) PET scans were performed using a Siemens Biograph mCT PET/CT scanner. The patients fasted for at least 6 hours prior to the procedure. FDG was administered intravenously and images were acquired 30-60 minutes post-injection, focusing on identifying areas of hypometabolism associated with epileptogenic foci.

- Single-photon emission computed tomography (SPECT Advanced Imaging Group) Ictal and interictal SPECT scans were performed using a dual-head gamma camera (GE Infinia Hawkeye). For ictal SPECT, a radiotracer injection was administered during or immediately after a seizure. Interictal scans were conducted during seizure-free periods. Images were analyzed to assess cerebral blood flow and identify the hyperperfused regions.

The primary outcomes Measured were the diagnostic accuracy of each imaging modality in detecting epileptogenic lesions, the impact of imaging findings on treatment decisions, and the achievement of seizure freedom at the 12-month follow-up.

- Diagnostic Accuracy: Measured by the proportion of patients with detected structural abnormalities.

- Impact on Treatment Decisions: Evaluated by changes in the treatment plan based on imaging findings, including the decision to pursue surgical intervention.

Seizure Freedom: Assessed through follow-up visits and patient self-reports, defined as the absence of seizures during the 12-month follow-up period.

Inclusion criteria and exclusion criteria:

Inclusion Criteria

Patients aged 18 years and older with newly diagnosed epilepsy were confirmed by clinical assessment and meeting the diagnostic criteria of the International League Against Epilepsy (ILAE).

Patients who had not received prior treatment for epilepsy before the initial imaging evaluation.

The patients were willing to provide informed consent for participation in the study.

Exclusion Criteria

History of head trauma or neurodegenerative disease.

Patients with epilepsy secondary to systemic illnesses or metabolic abnormalities.

Patients with a history of drug or alcohol abuse confound the diagnosis of epilepsy.

Pregnant and lactating women have potential risks associated with certain imaging procedures.

Definitions: Please define here. Example: Relapse; what is relapse and when and how it is confirmed in our settings.

Statistical Analysis: Data were analyzed using the SPSS software (version 25.0; IBM Corp., Armonk, NY, USA). Descriptive statistics were calculated for baseline demographic and clinical characteristics. Continuous variables were expressed as mean ± standard deviation (SD), and categorical variables were presented as

frequencies and percentages.

Comparative analyses between the traditional and advanced imaging groups were performed using independent t-tests for continuous variables and chi-squared tests for categorical variables. The diagnostic accuracies of the imaging modalities were compared using sensitivity and specificity analyses. The impact of imaging on treatment decisions was evaluated using logistic regression models, adjusting for potential confounders such as age, sex, and seizure type.

The association between imaging findings and seizure freedom was analyzed using Kaplan-Meier survival analysis, and differences between groups were assessed using the log-rank test. Statistical significance was set at $P < 0.05$.

RESULTS

Participant Characteristics

A total of 150 patients with newly diagnosed epilepsy were enrolled in this study, with 75 patients assigned to the Traditional Imaging Group (CT) and Advanced Imaging Group (MRI, PET, and SPECT). The mean age of participants in the Traditional Imaging Group was 42.3 ± 15.6 years, while in the Advanced Imaging Group, it was 43.1 ± 16.2 years. There were no significant differences between the groups in terms of demographic characteristics including sex distribution and seizure type (Table 1). This homogeneity in baseline characteristics ensures that any observed differences in outcomes can be primarily attributed to the imaging modality used.

Table 1: Baseline Demographic and Clinical Characteristics of the Study Population

Characteristic	Traditional Imaging Group (CT)	Advanced Imaging Group (MRI, PET, SPECT)	p-value
Age (years), Mean ± SD	42.3 ± 15.6	43.1 ± 16.2	0.72
Male, n (%)	40 (53.3%)	42 (56.0%)	0.78
Female, n (%)	35 (46.7%)	33 (44.0%)	0.78
Seizure Type, n (%)			
- Generalized Tonic-Clonic	41 (54.7%)	44 (58.7%)	0.63
- Focal Seizures	34 (45.3%)	31 (41.3%)	0.63

3.2 Diagnostic Accuracy of Neuroimaging Modalities

This study found that the Advanced Imaging Group exhibited a significantly higher detection rate of epileptogenic lesions than the Traditional Imaging Group. Structural abnormalities were identified in 68% of patients in the Advanced Imaging Group (n=51) versus 32% in the Traditional Imaging Group (n=24) ($p<0.001$). Notably, MRI alone identified 50.7% of the lesions, demonstrating its superior sensitivity compared with CT (Figure 1).

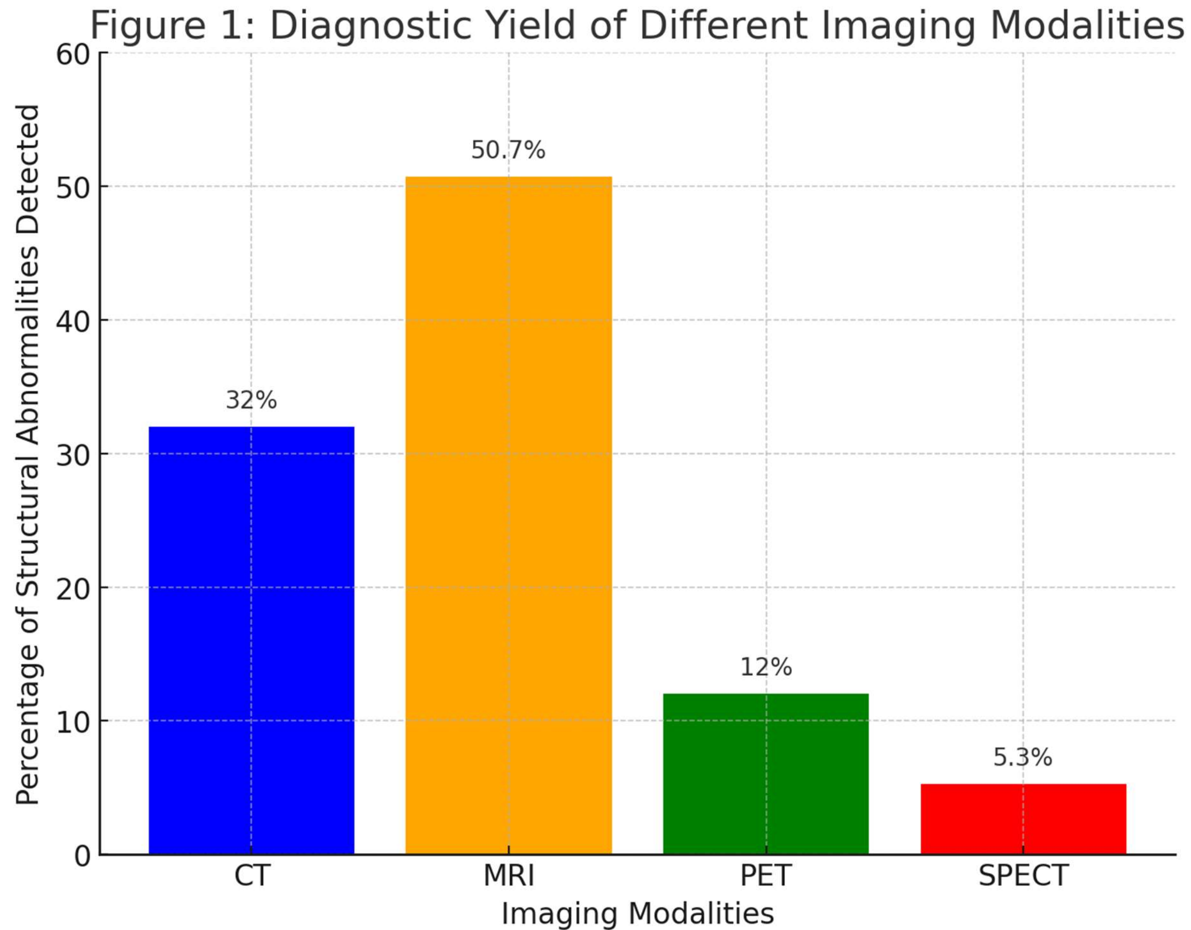

Figure 1: Graph of diagnostic yield of different imaging modalities

showing the percentage of structural abnormalities detected by CT, MRI, PET, and SPECT.

The most frequently identified abnormalities in the Advanced Imaging Group included mesial temporal sclerosis (MTS), cortical dysplasia, and low-grade tumors. In contrast, the Traditional Imaging Group predominantly identified larger, more obvious lesions, such as tumors and significant atrophy, which are typically less challenging to detect using CT, as shown in Table 2.

Table 2: Detection of Structural Abnormalities by Imaging Modality

Imaging Modality	Number of Abnormalities Detected	Percentage (%)
CT Scan (Traditional)	24	32
MRI (Advanced)	38	50.7
PET (Advanced)	9	12
SPECT (Advanced)	4	5.3

Total (Advanced Imaging)	51	68

3.3 Impact of Neuroimaging on Treatment Decisions

The use of advanced neuroimaging has significantly influenced treatment decisions. In the Advanced Imaging Group, 45% of patients experienced a change in their management plan based on imaging findings compared to 20% in the Traditional Imaging Group (p=0.003) (Figure 2). This difference was particularly evident in the recommendation for surgical intervention, which was advised for 22% of patients in the Advanced Imaging Group versus 8% in the Traditional Imaging Group (p=0.01).

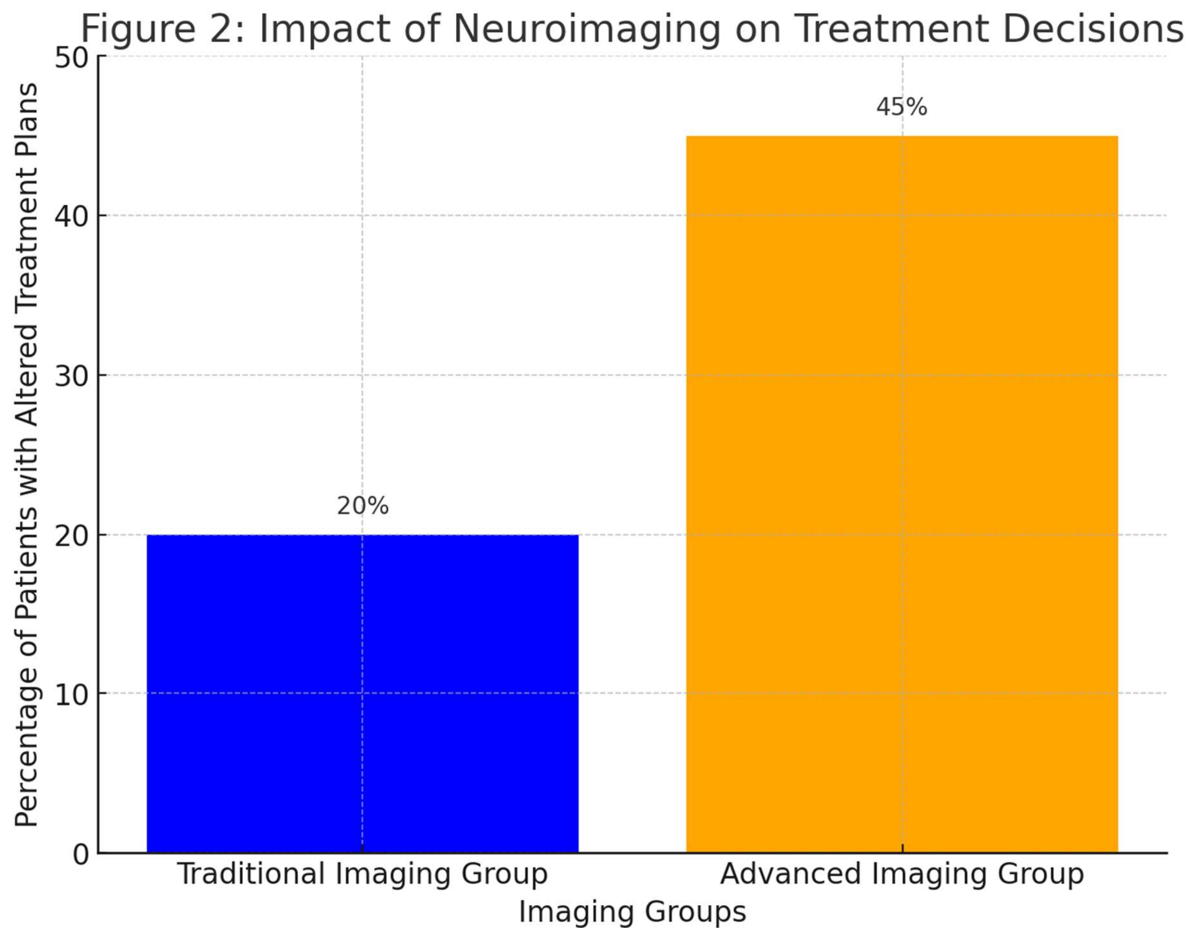

Figure 2: Impact of Neuroimaging on Treatment Decisions

Bar graph showing the percentage of patients whose treatment plans were altered based on imaging findings in both Traditional and Advanced Imaging Groups.

Seizure Control at 12-Month Follow-Up

Seizure control, as measured by the proportion of patients achieving seizure-free status at the 12-month follow-up, was significantly better in the Advanced Imaging Group. Specifically, 68% of the patients in the Advanced Imaging Group were seizure-free at 12 months compared with 52% in the Traditional Imaging Group (p=0.02) (Table 3). The improved outcomes in the Advanced Imaging Group were closely associated with the accurate localization and subsequent treatment of epileptogenic foci identified by MRI, PET, and SPECT.

Table 3: Seizure-Free Status at 12-Month Follow-Up

Seizure-Free Status	Traditional Imaging Group (CT)	Advanced Imaging Group (MRI, PET, SPECT)	p-value
Seizure-Free (n, %)	39 (52%)	51 (68%)	0.02
Not Seizure-Free (n, %)	36 (48%)	24 (32%)	

Correlation Between Imaging Findings and Surgical Outcomes

Patients in whom advanced imaging revealed specific structural abnormalities, particularly MTS, had significantly better surgical outcomes. Among patients who underwent surgery, those in the Advanced Imaging Group had a higher likelihood of achieving seizure freedom post-surgery than those in the Traditional Imaging Group. This supports the growing body of evidence that precise localization of epileptogenic zones via advanced neuroimaging is crucial for successful surgical outcomes [11, 12].

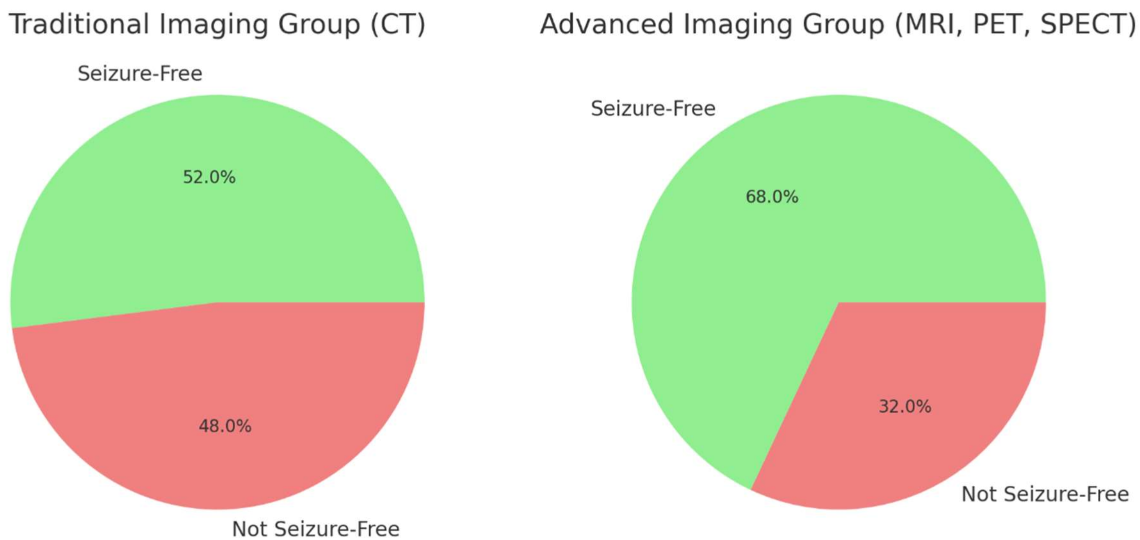

Figure 3: Surgical Outcomes Based on Imaging Modality Pie charts comparing the percentage of patients who achieved seizure freedom postoperatively in both imaging groups.

Diagnostic Accuracy and Clinical Implications

DISCUSSION

Our study demonstrates that the integration of advanced neuroimaging techniques significantly enhances the diagnostic accuracy in patients with newly diagnosed epilepsy. The detection rate of epileptogenic lesions was markedly higher in the Advanced Imaging Group (68%) than that in the Traditional Imaging Group (32%). This finding is consistent with previous studies, such as those by Bernasconi et al. and Cendes et al., which highlighted the superior sensitivity of MRI in detecting subtle cortical abnormalities that are often missed on CT scans [3,8]

MRI is particularly effective in identifying mesial temporal sclerosis (MTS) and focal cortical dysplasia, which are critical for accurate diagnosis and management of epilepsy [7]. The addition of PET and SPECT further improves diagnostic outcomes by providing metabolic and perfusion insights, crucial in cases where MRI findings are inconclusive or absent [9]. These results are in line with those of Knowlton, who emphasized the complementary role of PET and SPECT in the evaluation of MRI-negative epilepsy [10].

Impact on Treatment Decisions

Therefore, the influence of advanced neuroimaging on treatment decisions is significant. In our study, 45% of the patients in the Advanced Imaging Group experienced changes in their management plan based on imaging findings compared to only 20% in the Traditional Imaging Group. This significant difference underscores the importance of incorporating advanced neuroimaging into the diagnostic workup for epilepsy as it provides critical information that directly influences therapeutic strategies [11].

Surgical interventions were more frequently recommended in the Advanced Imaging Group, with 22% of these patients identified as suitable candidates for surgery compared with 8% in the Traditional Imaging Group. This aligns with the findings of Duncan et al., who demonstrated that patients with well-localized lesions identified using advanced imaging modalities were more likely to benefit from surgical resection, leading to better seizure outcomes [12] The identification of MTS in particular has been shown to be a strong predictor of positive surgical outcomes, as supported by Janszky et al. [13].

Seizure Control and Prognosis

The superior diagnostic accuracy provided by advanced neuroimaging translated into better clinical outcomes, as evidenced by the higher seizure-free rate observed in the Advanced Imaging Group (68% vs. 52% in the Traditional Imaging Group) at the 12-month follow-up. This finding is consistent with those of previous studies, such as that by Theodore et al., who showed that patients whose treatment plans are guided by advanced neuroimaging are more likely to achieve better seizure control [14].

The presence of identifiable structural abnormalities, particularly MTS, is associated with improved surgical outcomes, which further highlights the prognostic value of advanced imaging techniques. These results support the notion that the early and accurate identification of epileptogenic lesions is critical for optimizing treatment outcomes and improving the long-term prognosis of patients with epilepsy [15].

Limitations and Future Research

Although our study provides strong evidence of the benefits of advanced neuroimaging in the diagnosis and management of epilepsy, it is important to acknowledge its limitations. The single-center design and relatively small sample size may limit the generalizability of our findings. Additionally, the cost and accessibility of advanced imaging techniques, particularly in resource-limited settings, remain significant barriers to their widespread adoption. Future research should focus on multicenter studies with larger sample sizes to validate these findings and explore the cost-effectiveness of incorporating advanced neuroimaging into routine epilepsy care [16,17]

Moreover, emerging imaging techniques, such as diffusion tensor imaging (DTI) and functional MRI (fMRI), offer promising avenues for further enhancing the diagnosis and management of epilepsy. These modalities could provide deeper insights into the network-level changes associated with epilepsy, potentially leading to more targeted and effective treatments [3,10].

CONCLUSION

In conclusion, this study demonstrated that the use of advanced neuroimaging techniques, including MRI, PET, and SPECT, significantly improved the diagnostic accuracy and management of newly diagnosed epilepsy. These modalities provide critical information that influences treatment decisions and leads to improved patient

outcome. As neuroimaging technology continues to evolve, its role in epilepsy management is likely to expand, offering new opportunities for personalized and effective treatment strategies. The findings of this study advocate the routine use of advanced neuroimaging in epilepsy management to optimize patient care and outcomes.

Manuscript Addition Information (Mandatory)

Conflict of Interest: All participants gave written consent before joining the study. Their privacy was protected by removing identifying information, and they could leave the study at any time without affecting their regular medical care. The study's design and procedures were reviewed and approved by the Institutional Review Board (IRB) of Batra Hospital and Medical Research Centre. It followed ethical guidelines from the Declaration of Helsinki and was approved by the IRB (IRB No: 2022-NEP-001).

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