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Advances in neuroimaging for diagnosis and monitoring of epilepsy.

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Introduction

Epilepsy is a chronic neurological disorder characterized by recurrent unprovoked seizures resulting from abnormal, excessive, or synchronous neuronal activity in the brain. It affects millions of individuals worldwide and has diverse etiologies, clinical manifestations, and outcomes. Accurate diagnosis and effective monitoring of epilepsy are essential for guiding treatment strategies, assessing prognosis, and improving patient quality of life. Neuroimaging plays a critical role in this process, allowing clinicians to visualize structural, functional, and metabolic abnormalities that underlie seizure disorders [1]. Over the past few decades, significant advances in neuroimaging have transformed the diagnosis and management of epilepsy, enabling earlier detection of epileptogenic lesions, better understanding of seizure networks, and more precise surgical planning for drug-resistant cases. These developments have led to a paradigm shift from purely clinical and electroencephalographic evaluation toward an integrated approach that combines neuroimaging with other diagnostic modalities [2].

Magnetic resonance imaging remains the gold standard for structural brain evaluation in epilepsy. High-resolution MRI provides unparalleled soft tissue contrast and spatial resolution, allowing for the identification of structural lesions such as hippocampal sclerosis, cortical dysplasia, low-grade tumors, vascular malformations, and post-traumatic or post-infectious scarring. Advances in MRI technology, including higher field strengths such as 3 Tesla and even 7 Tesla systems, have improved lesion detection, particularly for subtle abnormalities that may be invisible on conventional imaging. Optimized MRI protocols tailored for epilepsy, often referred to as epilepsy-specific protocols, include thin-slice 3D T1-weighted imaging, high-resolution T2-weighted and FLAIR sequences, and coronal imaging perpendicular to the hippocampus. These improvements have enhanced the sensitivity of MRI in detecting epileptogenic foci, which is especially important in cases of MRI-negative epilepsy where traditional scans fail to reveal an abnormality [3].

Beyond conventional MRI, advanced structural imaging techniques have expanded the diagnostic capabilities of neuroimaging in epilepsy. Diffusion tensor imaging is particularly valuable for assessing white matter integrity and connectivity in patients with epilepsy. It measures the diffusion of water molecules along axonal fibers, providing information on microstructural integrity that is not visible on standard MRI. DTI has revealed white matter abnormalities in both lesional and non-lesional epilepsy, suggesting that epilepsy may be associated with widespread network disruptions rather than being confined to a focal lesion. Quantitative analysis of diffusion parameters can help identify subtle structural changes and guide surgical planning by mapping white matter tracts that must be preserved [4].

Functional neuroimaging techniques have also become indispensable in the evaluation of epilepsy. Functional MRI is used to map brain activity related to specific tasks or resting-state networks. In pre-surgical evaluation, fMRI helps identify eloquent cortical regions responsible for critical functions such as language and motor control, allowing surgeons to minimize postoperative deficits. Resting-state fMRI has shown promise in revealing abnormal connectivity patterns in epilepsy patients, potentially providing biomarkers for disease activity and treatment response. Functional imaging not only aids in identifying seizure networks but also offers insights into the broader impact of epilepsy on brain function [5].

Conclusion

In conclusion, advances in neuroimaging have revolutionized the diagnosis and monitoring of epilepsy, offering unprecedented insights into the structural, functional, and metabolic underpinnings of seizure disorders. High-resolution MRI, advanced structural techniques, functional imaging, metabolic mapping, and multimodal integration have greatly improved the ability to localize epileptogenic zones, particularly in challenging MRI-negative cases. These developments have enhanced surgical planning, reduced postoperative complications, and expanded the range of patients who can benefit from curative interventions. Moreover, neuroimaging now plays a vital role in monitoring treatment effects and disease progression, offering objective biomarkers that complement clinical evaluation.

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