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THE ROLE OF DIFFUSION WEIGHTED MR IMAGING IN DETECTION OF BRAIN LESION

Original Research

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ABSTRACT

Background: Brain lesions, encompassing a spectrum of pathological alterations in brain tissue, pose significant diagnostic challenges due to their often subtle manifestations on traditional imaging techniques. Early and accurate detection is crucial for effective treatment planning and patient management.

Objective: To assess the efficacy of diffusion-weighted imaging (DWI) in the detection of brain lesions and to compare its diagnostic accuracy with histopathological findings.

Methods: This analytical cross-sectional study was conducted at the Department of Radiology, Islamabad Diagnostic Center, Faisalabad, from September 2024 to October 2024. A total of 88 patients with brain lesions identified on MRI underwent DWI. These lesions were classified as neoplastic or non-neoplastic based on diffusion restriction patterns. Correlation with histopathological results was performed, and the sensitivity, specificity, positive and negative predictive values, and diagnostic accuracy of DWI were evaluated. The Chi-square test was used to analyze the association between diffusion restrictions and the presence of brain lesions.

Results: DWI demonstrated a sensitivity of 93.62%, specificity of 92.68%, positive predictive value of 93.62%, negative predictive value of 92.68%, and a diagnostic accuracy of 93.18% in detecting brain lesions. A statistically significant p-value of 0.001 was obtained, confirming the efficacy of DWI in the diagnostic process.

Conclusion: Diffusion-weighted imaging is a non-invasive, highly sensitive, and specific modality that significantly enhances the detection of brain lesions. It is recommended that DWI be used in conjunction with conventional imaging techniques to improve diagnostic accuracy.

Keywords: Brain Lesions, Diagnostic Accuracy, Diffusion Weighted Imaging, Histopathology, Magnetic Resonance Imaging, Neoplastic, Non-neoplastic.

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INTRODUCTION

Brain lesions present unique diagnostic challenges due to the complexity and often subtle presentation in conventional imaging modalities. Accurate and early detection of these lesions is crucial for effective treatment planning and patient management. Diffusion-weighted imaging (DWI), an advanced MRI technique, has proven to be a critical tool in addressing these challenges. DWI provides unique insights into the movement of water molecules within brain tissue, which is particularly valuable in distinguishing different types of lesions, such as tumors, abscesses, demyelinating lesions, and other neuro-abnormalities (1). The process of DWI involves quantifying the diffusion of water molecules, offering a window into cellular density and structural integrity at the microstructural level. Lesions tend to alter water mobility patterns due to cellular changes, edema, or necrosis. DWI can detect these alterations effectively, often before they are visible on conventional MRI sequences. For instance, brain tumors generally exhibit restricted diffusion due to the densely packed cells within the lesions, while abscesses display unique diffusion patterns related to their infectious components (2).

As a diagnostic tool, DWI has become indispensable in neuroimaging for both the detection and characterization of various brain lesions. By exploiting the diffusion properties of water molecules in tissue, DWI achieves high sensitivity to changes in cellular density and microstructural alterations. This sensitivity is critical for identifying complex brain pathologies with exceptional precision (3). The diagnostic power of DWI extends to the evaluation of neoplastic lesions, including gliomas, meningiomas, astrocytomas, schwannomas, and medulloblastomas, as well as metastatic brain lesions, facilitating accurate differentiation between benign and malignant growths (4,5). Furthermore, DWI shows significant efficacy in assessing non-neoplastic brain abnormalities. In cases of demyelinating diseases, it detects microstructural changes in white matter, aiding in the differential diagnosis from other white matter disorders (6). It is also instrumental in identifying vascular malformations, providing essential data on regions of altered diffusion that may indicate associated complications (7). For specific cystic formations like epidermoid cysts, DWI offers a distinct diagnostic advantage by differentiating these lesions from other cystic anomalies, such as arachnoid cysts, based on their unique diffusion patterns (8).

The ability of DWI to provide precise diagnostic information is essential for modern treatment planning of brain lesions. By accurately characterizing the lesion type, cellularity, and extent, DWI contributes significantly to tailored therapeutic approaches, ranging from surgical interventions to radiation and pharmacological treatments (9,10). This precision in diagnosis and targeted treatment planning is pivotal in improving patient outcomes, underscoring the transformative role of DWI in contemporary neuroimaging and brain lesion management (11). The objective of utilizing DWI in clinical practice is to enhance the diagnostic accuracy for brain lesions, thereby optimizing patient management and treatment outcomes. This approach underscores the importance of integrating advanced imaging techniques in the diagnostic protocol to ensure comprehensive evaluation and effective intervention strategies.

METHODS

The study was conducted at the Department of Radiology, Islamabad Diagnostic Centre, Faisalabad, over a period from July to October 2024. It utilized a computer-assisted search of MR reports to initially identify 120 brain lesions where diffusion-weighted imaging (DWI) had been performed, and images were available on PACS for review. However, 32 patients were excluded based on exclusion criteria including the non-availability of histopathology results or loss to follow-up. Systematic observational data collection commenced with the enrollment of eligible patients during their clinic visits, subsequent to obtaining informed consent. Comprehensive clinical data, such as patient demographics and presenting symptoms, were meticulously documented. MRI scans were conducted using a Philips MRI 1.5T machine, incorporating protocols such as Axial T1, T2, Sagittal T2, Coronal FLAIR, and DWI Axial to comprehensively assess neuro-pathologies. Diffusion sensitizing gradients were applied at sensitivities of b = 0, 500, and 1000 s/mm^2 to optimize the detection of microstructural changes in brain tissue.

The inclusion of patients in the study was particularly focused on those exhibiting diffusion restriction, defined as hyperintense signals on diffusion imaging paired with corresponding hypointense signals on apparent diffusion coefficient (ADC) maps. This criterion was central to identifying patients whose brain lesions were likely to yield significant diagnostic insights upon further analysis. All MRI images were interpreted by four consultant radiologists with expertise in MRI, including DWI. The reports were generated in both soft and hard copies. Data extraction from each report was performed systematically, ensuring detailed capture of diffusion-related findings. The final diagnosis for each patient was confirmed via histopathology.

The ethical approval for this study was granted by the institutional ethical review committee, with an exemption from further ethical review. Data analysis was carried out using the Statistical Package for Social Sciences (SPSS) version 23. Statistical measures such as mean and standard deviation were calculated for quantitative data, while frequencies were tabulated for categorical data. To ascertain the diagnostic efficacy of DWI, measures of sensitivity, specificity, positive and negative predictive values, and overall accuracy were computed. The association between diffusion restrictions and the presence of brain lesions was statistically evaluated using the Chi-square test, considering a p-value of < 0.05 as significant. The rationale behind employing specific statistical methods was aligned with

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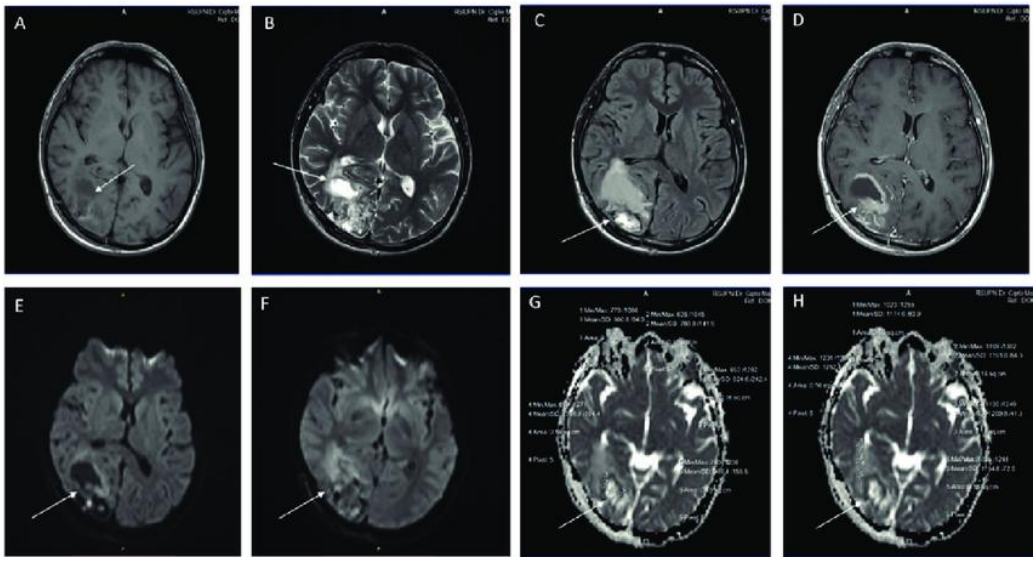
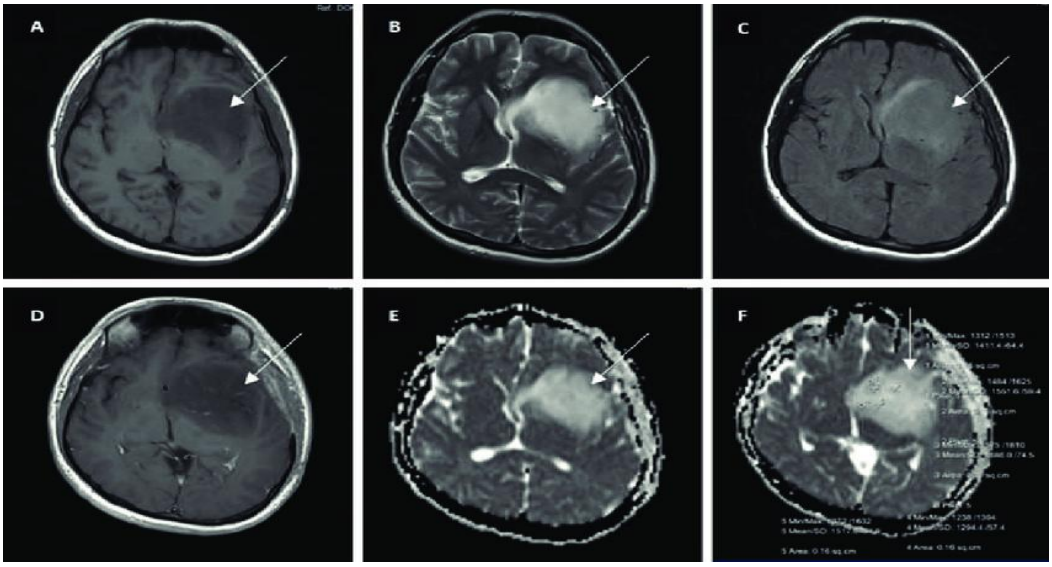
the study's objectives to assess the diagnostic accuracy of DWI in detecting brain lesions. This approach facilitated a robust analysis of the imaging data, enabling precise characterization of lesion types and their correlation with clinical outcomes.



High grade glioma (WHO Grade III). A: T1-weighted image (T1WI); B: T2-weighted image (T2WI); C: Fluid-Attenuated Inversion Recovery (FLAIR); D: T1WI-post contrast; E: diffusion-weighted imaging (DWI); F: DWI; G: tumoral apparent diffusion coefficient (ADC); H: peritumoral ADC.



Low grade glioma (WHO Grade II). A: T1-weighted image (T1WI); B: T2-weighted image (T2WI); C: Fluid-Attenuated Inversion Recovery (FLAIR); D: T1WI-post contrast; E: diffusion-weighted imaging (DWI); F: tumoral apparent diffusion coefficient (ADC).

RESULTS

In the conducted study, the most frequent clinical manifestations observed included neurological deficits in 67% of cases, headaches in 42%, vomiting in 13.6%, vertigo in 21.6%, and seizures in 13.6%, with all symptoms related to the location of the lesion. The patient cohort comprised an equal distribution of genders, with 50% male and 50% female, across a wide age range from 4 to 82 years, and an average age of 45 ± 19 years. The mean lesion size was calculated to be approximately 32.33 mm.

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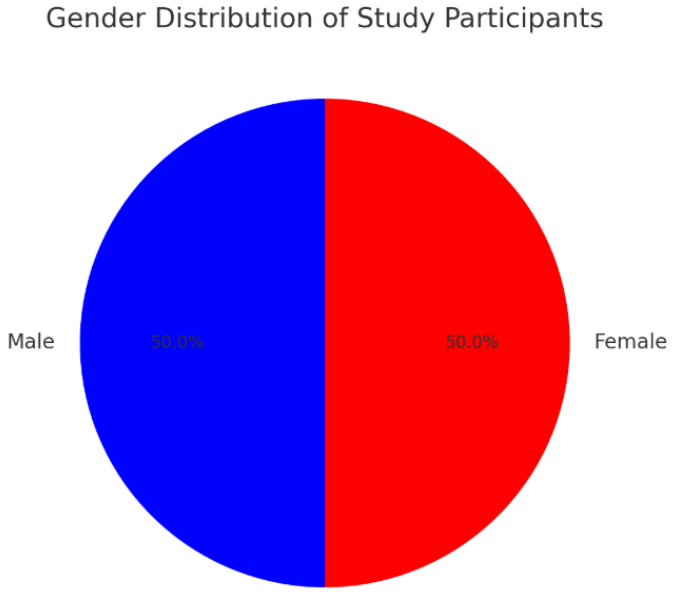

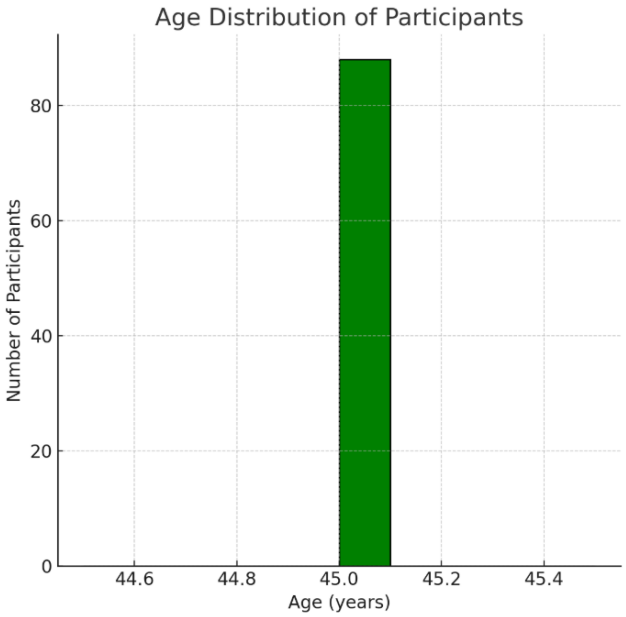

Of the 88 cases analyzed, diffusion restriction, characterized by high signals on diffusion-weighted imaging and corresponding low signals on apparent diffusion coefficient (ADC) images, was observed in 54 lesions (61%), while 34 lesions (39%) did not demonstrate diffusion restriction. Diagnostic outcomes from DWI MR examinations revealed that 43 patients (49%) were diagnosed with brain lesions, whereas 45 patients (51%) were found to have conditions not classified as brain lesions, with varied etiologies. Histopathological evaluations corresponded closely with imaging findings, diagnosing 45 patients (51%) with brain lesions. These included primary neoplastic lesions, various grades of gliomas, glioblastomas, metastases, meningiomas, schwannomas, astrocytomas, craniopharyngiomas, and a few cases of hemangiopericytomas, medulloblastomas, lymphomas, ependymomas, and osseous lesions invading brain parenchyma. Non-neoplastic conditions identified included epilepsy, demyelination, choroid plexus carcinomas, tuberculosis, hemorrhagic infarcts, granulomatous inflammation, epidermoid and arachnoid cysts, vasculitis, meningoencephalitis, and cavernomas.

The diagnostic efficacy of DWI was notable, with 95.5% of the brain lesions demonstrating diffusion restriction. The performance of DWI in distinguishing brain lesions from other pathologies was quantified, showing a sensitivity of 93.62%, specificity of 92.68%, positive predictive value of 93.62%, negative predictive value of 92.68%, and an overall diagnostic accuracy of 93.18%. This comprehensive evaluation underlines the utility of DWI in the accurate detection and characterization of brain lesions, emphasizing its importance in clinical diagnostics. However, the study could benefit from a deeper analysis of the correlation between lesion size and diffusion characteristics, as well as a more detailed exploration of the impact of varied etiologies on diagnostic accuracy.

Table I: Accuracy of diffusion weighted imaging.

True positive	**n = 44**
True negative	n = 38
False positive	n = 03
False negative	n = 03
Sensitivity	93.62%,
Specificity	92.68%
Positive predictive value	93.62%
Negative predictive value	92.68%

n = Number of cases

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DISCUSSION

Diffusion-weighted imaging (DWI) has established itself as an essential tool in the assessment of brain lesions by capturing pathophysiological changes at a cellular level. Its high sensitivity and specificity are attributable to its unique mechanism, which detects restricted water diffusion typically seen in hypercellular environments, such as neoplastic and ischemic tissues. This characteristic has been consistently corroborated by previous research, which links restricted diffusion patterns to high cellular density and cytotoxic edema. The low signals on apparent diffusion coefficient (ADC) images complement this by effectively excluding conditions characterized by free water diffusion, such as cystic or inflammatory lesions (12). The study reported high diagnostic values across sensitivity, specificity, positive and negative predictive values, and accuracy, aligning closely with findings from previous literature. The strong correlation between DWI findings and histopathological results underscores its reliability. The majority of brain lesions in this study, often associated with malignant tumors and acute infarctions, exhibited restricted diffusion—a feature that aligns with the dense cellular architecture and necrotic cores seen in conditions like glioblastomas and metastatic lesions, explaining the 95.5% concordance of diffusion restriction with brain lesions in the sample. In contrast, non-neoplastic conditions such as vasculitis or infections often presented variable DWI patterns, reflecting the diverse pathophysiological underpinnings of these conditions (15).

DWI's capability to differentiate between neoplastic lesions and other pathologies like demyelinating diseases, cysts, and vascular abnormalities highlights its specificity. The distinction between types of cysts, such as arachnoid and epidermoid cysts based on their diffusion properties, is crucial for accurate treatment planning and prognostication. This diagnostic capability is supported by findings from other studies which emphasize DWI's role in differentiating granulomatous inflammation from neoplasms based on diffusion characteristics (16). Additionally, the reported diagnostic accuracy of DWI aligns with benchmarks from prior meta-analyses, often exceeding 90%, underscoring its efficacy in brain lesion detection. The modality's non-invasive nature and rapid acquisition times make it particularly valuable in urgent and critical care settings, promoting its use as a frontline imaging technique, especially in areas where more advanced imaging modalities may be unavailable (18).

Despite the high sensitivity and specificity demonstrated, the study noted exceptions where three neoplastic cases did not show diffusion restriction, presenting with high ADC values. Similarly, three non-neoplastic cases showed diffusion restriction, highlighting ongoing debates and the presence of conflicting reports in the literature. These findings point to the inherent limitations of DWI, emphasizing the need for cautious interpretation in conjunction with conventional MRI sequences. This study, being a single-center study, may exhibit a selection bias, and the conjunction of DWI with routine MRI sequences might lead to diagnostic bias. These limitations suggest that while DWI is invaluable in neuroradiology, it must be integrated carefully with other diagnostic tools for optimal accuracy. The insights provided by DWI are invaluable for clinical decision-making. Looking forward, the integration of DWI with other imaging modalities like perfusion and diffusion tensor imaging holds promise for enhancing diagnostic precision, particularly in complex cases with overlapping features of neoplastic and non-neoplastic pathologies, thus paving the way for more nuanced and informed therapeutic strategies.

CONCLUSION

The utility of diffusion-weighted imaging (DWI) in the diagnostic landscape of neuroradiology is well-established through this study. By providing a detailed visualization of cellular-level changes within the brain, DWI enhances the accuracy of diagnosing various brain lesions. Its ability to distinguish between different types of pathologies—be they neoplastic or non-neoplastic—is especially valuable in formulating precise treatment plans. Despite the challenges presented by cases that deviate from typical diffusion patterns, the integration of DWI with other imaging techniques promises to refine its diagnostic capabilities further. This study underscores the significant role of DWI in advancing clinical outcomes and supports ongoing advancements that aim to harness its full potential in medical imaging.

AUTHOR CONTRIBUTIONS

Author	Contribution
Adeel Shah	Conceptualization, Methodology, Formal Analysis, Writing - Original Draft, Validation, Supervision
Tayyaba Ayub	Methodology, Investigation, Data Curation, Writing - Review & Editing
Ahmad Mehmood	Investigation, Data Curation, Formal Analysis, Software
Hassnain Ijaz	Software, Validation, Writing - Original Draft
Momna Aslam	Formal Analysis, Writing - Review & Editing
Amna Noreen	Writing - Review & Editing, Assistance with Data Curation

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