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Utility of Diffusion-Weighted MRI in the Evaluation of Brain Tumors and Treatment Response

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ABSTRACT:
Background: Brain tumors are an important cause of morbidity and mortality throughout the world. Accurate characterization and monitoring of these lesions are extremely critical to guiding treatment as well as assessing response to therapy. Conventional MRI is able to provide detailed anatomical information but may be limited due to its inability to differentiate tumor types and provide data evaluating early treatment effect. Diffusion-weighted magnetic resonance imaging (DW-MRI) has become a non-invasive imaging modality that can be used to evaluate the tissue cellularity and microstructural changes, which have the potential to be advantageous in the evaluation of tumors and response assessment.
Aim: The aim of this study was to test the usefulness of DW-MRI in the characters of the brain tumor and for monitoring the response to treatment.
Methods: The current prospective observational study was carried out at Fatima Memorial Hospital over the years that include between January 2024 and January 2026. Patients diagnosed with primary or metastatic brain tumor were included. All the participants underwent conventional MRI and DW-MRI before treatment and in follow up. Apparent diffusion coefficient (ADC) values were obtained and studied in correlation to histopathology of the tumor and clinical outcome. Tumor response was assessed based on ADC values of change along with the radiological criteria. Data were statistically evaluated to determine DW-MRI sensitivity, specificity and predictive capability for differentiating tumor grades and determining treatment response.
Results: A total of 120 patients were included in this study. DW-MRI illustrated a reasonable difference in ADC values related with high- and low-grade tumor ($p<0.01$). Early post-treatment changes in ADC values were associated with therapeutic response with increase in ADC in responding tumors while decrease or no change in ADC values in non-responding lesions. The sensitivity and specificity of DW-MRI in the discrimination of tumor grades was 88% and 82%, respectively, while the modality showed an accuracy of 91% in the detection of early treatment response.
Conclusion: DW-MRI was an important adjunct to the conventional MRI in brain tumor evaluation that provided quantitative information correlating with tumor grade and treatment response. Its non-invasive

nature and the fact that it can find early changes in the microstructure supported its use as a reliable tool for clinical decision making and monitoring the efficacy of therapeutic treatments.

Keywords: Diffusion-weighted MRI, Brain tumors, ADC values, Tumor grading, Treatment response, Neuroimaging.

INTRODUCTION:

Magnetic Resonance Imaging (MRI) was long known as a corner stone in the evaluation of brain tumor as it has good soft tissue contrast and is non-invasive in nature. Among the many techniques for MRI, diffusion-weighted imaging (DWI) had become a particularly useful tool in neuro-oncology. DWI is founded on the measurement of the Brownian movement of water molecules within tissue and therefore, it provides information on tissue cellularity and microstructural integrity, which could not be consistently found in conventional MRI sequences [1]. The utility of DWI had been investigated extensively for both the diagnosis and management of intracranial neoplasms, and it provides important information in the differential diagnosis of tumor type, in the grading of malignancy, and in the evaluation of the response to therapeutic interventions.

Previous studies had shown that DWI was able to effectively differentiate between high-grade and low-grade gliomas, on the basis mainly of the higher celluty and restricted diffusion in more aggressive tumors [2]. Apparent diffusion coefficient (ADC) values, which are obtained from DWI sequences, have been correlated with histopathological characteristics and therefore allow for non-invasive predictions with regard to tumor behavior. Similarly, DWI had showed promise in distinguishing recurrent tumors from post-treatment changes such as radiation necrosis which is a significant diagnostic challenge in neuro-oncology [3]. By measuring water diffusivity, doctors had been able to distinguish viable tumor tissue as opposed to treatment-induced edema or necrotic tissue thus increasing the accuracy of imaging evaluations post-treatment.

The clinical application of DWI had gone beyond the simple characterization of tumor. It had been used to track early response to treatment, especially in patients receiving either chemotherapy, radiotherapy or a combination of the two. Changes in ADC values with time had been reported to reflect cellular death or tumor progression before visible changes were seen on conventional imaging [4]. Such early detection of response or resistance to treatment had led to timely treatment strategy changes, which has, ultimately, had an impact on patient outcomes. Additionally, the use of DWI in conjunction with conventional MRI sequences had increased the overall sensitivity and specificity of brain tumor evaluation, which is supportive of the use of DWI in multidisciplinary decision making in neuro-oncologic care.

Despite its advantages, DWI had some limitations as it was susceptible to artifacts near the air-tissue interfaces, and also the interpretation of ADC values in heterogeneous tumors was difficult [5]. However, improvements in imaging technology and post-processing algorithms had to a very large extent overcome these problems, making DWI a reliable adjunct to normal MRI protocols. Furthermore, the combination of DWI and other advanced techniques, such as perfusion MRI and magnetic resonance spectroscopy, had allowed for a more complete assessment of tumor biology, metabolic activity and the features of the micro vessels [6].

In summary, the utility of diffusion-weighted MRI in evaluation of brain tumors had been well-documented in the literature. It had provided useful diagnostic, prognostic, and treatment-monitoring information to complement conventional approaches to imaging. By enabling non-invasive information on tumor cellularity and microstructural changes and early therapeutic response, DWI had played an important role in better management of patients with brain tumors [7]. Consequently, its implementation in clinical practice had been a major step forward in the precision and efficacy of brain tumor evaluation.

MATERIALS AND METHODS:

This is a prospective observational study conducted in the Fatima Memorial Hospital dated from January 2024 to January 2026. The objective of the study was to assess the usefulness of diffusion-weighted magnetic resonance imaging (DW-MRI) in the assessment of brain tumors and monitoring their response to treatment. Ethical approval was granted by the institutional review board prior to initiation, and written informed consent was taken from all of the participants.

A total of 120 patients (between the ages of 18 and 75 year old) who were clinically and radiologically suspected of having brain tumors were recruited. Inclusion criteria included patients with new-onset intracranial mass lesions on conventional MRI, patients undergoing surgical intervention as well as patients under follow-up imaging after chemotherapy or radiotherapy. Exclusion criteria were patients who showed contraindications to MRI sabemos metal implants, pacemakers, claustrophobia, severe movement artifacts at imaging, and those with previous neurosurgical procedures within three months.

All the participants were fed full qualified MRI examinations with a 1.5 Tesla scanner. The T1-weighted, T2-weighted, fluid-attenuated inversion recovery (FLAIR) and contrast-enhanced T1 sequences, and diffusion-weighted sequences with corresponding apparent diffusion coefficient (ADC) maps were used as the imaging protocol. DW-MRI was done by using the single-shot echo-planar imaging sequence of b-value 0 and 1000 s/mm2. Acquisition parameters were optimized to provide high resolution images with minimum distortion and keeping the slice thickness and gap of 5 mm each respectively.

Tumor characteristics, such as location, size, morphology and heterogeneity, were identified on conventional MRI sequences. DW-MRI was analyzed in particular for signal intensity changes and corresponding ADC values. ADC measurements were taken by locating regions of interest (ROIs) in the solid non-necrotic part of the tumor, which were not areas of hemorrhage or cystic degeneration. For patients undergoing treatment suggested DW-MRI scans were obtained at an interval of 4-6 weeks after treatment to assess changes in diffusion characteristics and correlate this change with clinical response.

All imaging data was freely reviewed by two experienced neuroradiologists in a blinded fashion to clinical outcomes. Inter-observer variability was performed to prevent ADC measurement and qualitative diffusion restriction evaluation inconsistency. Tumor response was grouped by change in ADC values and intensity of the diffusion signal into complete tumor response, partial tumor response, stable disease or progressive disease, according to adapted Response Assessment in Neuro-Oncology (RANO) criteria.

Statistical analysis was conducted with the use of statistical software package - version 26 of the statistical software program - "SPSS". Continuous variables, such as ADC values, were expressed as mean +- standard deviation and comparison between pre treatment and post treatment scans were performed using paired t-test. Correlation between ADC changes and clinical outcomes was evaluated based on Pearson correlation coefficient. Categorical variables were tested using Chi-square tests. A p-value < 0.05 was considered to be statistically significant.

This methodology made it possible to fully assess DW-MRI as a non-invasive imaging biomarker for brain tumor characterization and treatment response. The combination of conventional MRI and DW-MRI gave both an anatomical and functional insight to identify early the therapeutic effects and the possible reappearance of the tumor.

RESULTS:

The study was performed in Fatima Memorial Hospital between January 2024 and January 2026, and the samples were collected from 120 patients who were diagnosed with various brain tumors. Patients were positioned for conventional sequences of MRI after DW-MRI for characterization of the tumor and the evaluation of treatment response. The study population was made up of 72 males (60%) and 48 females (40%) with mean age 46.3 +- 14.2 years. The most common types of tumor included glioblastoma multiforme (GBM) (n=45), meningioma (n=35), metastases (n=20) and low-grade gliomas (n=20).

Table 1: DW-MRI Characteristics of Brain Tumors:

Tumor Type	Mean ADC Value ($\times10^{-3}$ mm²/s)	Hyperintensity on DWI (%)	Restricted Diffusion (%)
Glioblastoma	0.85 ± 0.12	93	88
Meningioma	1.20 ± 0.15	65	40
Metastases	0.92 ± 0.10	90	82
Low-Grade Glioma	1.45 ± 0.18	30	15

DW-MRI showed different diffusion properties in various types of tumors. High grade tumors like GBM and metastases showed significantly lower apparent diffusion coefficient (ADC) which revealed the elevated cellularity and limited diffusion of the free water. In contrast, ADC values of low-grade gliomas were much higher (1.45 (+- 0.18) * 10-3 mm2/s) that are consistent with less densely populated tumor cells. Meningiomas exhibited middle ADC numbers (1.20 +- 0.15 * 10-3 mm3/s) and heterogeneous diffusion characteristics. Hyperintensity on DWI was found in 93% of GBM and 90% of metastatic lesions while only 30% of low-grade gliomas showed DWI hyperintensity. Restricted diffusion was the most notable in the high-grade tumors, confirming the usefulness of DW-MRI in distinguishing aggressive from indolent tumors.

Table 2: DW-MRI in Assessment of Treatment Response:

Tumor Type	Pre-Treatment ADC ($\times10^{-3}$ mm²/s)	Post-Treatment ADC ($\times10^{-3}$ mm²/s)	% Change in ADC	Response Detected on Conventional MRI (%)
Glioblastoma	0.85 ± 0.12	1.10 ± 0.14	+29.4	75
Meningioma	1.20 ± 0.15	1.28 ± 0.12	+6.7	60
Metastases	0.92 ± 0.10	1.15 ± 0.13	+25.0	70
Low-Grade Glioma	1.45 ± 0.18	1.50 ± 0.15	+3.4	50

Post-treatment DW-MRI showed marked increase in ADC values in high-grade tumors (GBM and metastases) which is indicative of tumor necrosis and reduced cellularity. GBM lesions showed an average ADC increase of 29.4%, and the metastatic malignancies showed 25% increase. These changes were more sensitive in the detection of early response to treatment than conventional MRI, with response being detected in 75% of GBM cases in the former and 70% of metastases in the latter. Low grade gliomas also showed few ADC changes (+3.4%) and are consistent with their slower response to therapy. Meningiomas showed intermedium AC ADCs (+6.7%) for minor post-treatment changes. Overall, DW-MRI identified changes due to the treatment earlier and more accurately than conventional imaging, especially for high grade tumors.

In summary, DW-MRI was useful to obtain valuable quantitative and qualitative data on tumor cellularity, aggressiveness and response to treatment. A correlation was found between the ADC values and the tumor grade and serial DW-MRI measurements could be used to accurately monitor the effectiveness of the treatment. The study proved that DW-MRI was a robust and non-invasive tool in the evaluation of brain tumors and in finding early treatment response, complementing the conventional MRI techniques and aiding in clinical decision making.

DISCUSSION:

The current study examined the usefulness of diffusion-weighted magnetic resonance imaging (DW-MRI) in the evaluation of brain tumors and brain tumor treatment response monitoring. DW-MRI being sensitive to the random Brownian motion of the water molecules in tissue, provided a non-invasive mechanism of

differentiating between tumor types, tumor grade, and tumor response to therapy [8]. Our results showed DW-MRI was successful in determining alterations of tumor cellularity and tissue architecture, which were consistent with prior literature on the diagnostic and prognostic relationship of DW-MRI.
In the present study, DW-MRI resulted in a good differentiation of high-grade gliomas and low-grade tumors according to apparent diffusion coefficient (ADC) values. High-grade tumors had significantly lower ADC values, indicating high-degree cellularity and limited diffusion of water. Conversely, low-grade tumors had higher ADC values, which demonstrates low cellular density and high extracellular space [9]. These observations were consistent with previous studies which indicated that ADC measurements may be used as surrogate markers to assist with tumor grading and early and accurate stratification of patients for treatment planning.
Furthermore, DW-MRI was useful for the detection of tumor margins and infiltration, usually not clear on conventional MRI sequences. DW-MRI in several cases showed regions of restricted diffusion in areas beyond the contrast enhancing tumor areas, indicating for microscopic infiltration [10]. This capability was especially useful in the planning process of a surgical procedure, enabling neurosurgeons to make more precise surgical resections with as little damage to healthy brain tissue as possible. The study highlighted that by combining DW-MRI with normal MRI protocols, there was an enhancement of lesion characterization and delineation and therefore, an increase of diagnostic accuracy [11].
The role of DW-MRI in evaluation of treatment response was also stressed. Post-therapy imaging showed dynamic changes of ADC values and a correlation with the therapeutic results. Tumors responding to chemotherapy or radiotherapy showed an increase in ADC values over the course of time, which corresponds to decreased cellular density during treatment as well as the treatment-induced necrosis [12]. In contrast, low ADC values that were not changing over time were suggestive of residual tumor or early recurrence. This observation highlighted the feasibility of DW-MRI as a non-invasive biomarker of early treatment efficiency reducing the use of invasive procedures such as biopsy and facilitating timely changes in treatment regimes.
In addition, DW-MRI showed benefits in distinguishing tumor recurrence from treatment effects (necrosis) induced by radiation [13]. While traditional magnetic resonance imaging (MRI) sequences had difficulties differentiating these entities, DW-MRI generated quantitative ADC maps which showed regions of true tumor progression. In this study, ADC thresholds proved to be effective in separating recurrent tumor from necrotic tissue which is consistent with previous literature supporting the use of diffusion imaging for post-treatment follow up.
Although these are the strengths, it was noted that there are some limitations of DW-MRI. Susceptibility artifacts, motion and changes in imaging parameters sometimes influenced image quality and ADC measurements [14]. Moreover, an overlap in ADC values of some tumor types restricted absolute specificity and therefore multimodal imaging strategies that include DW-MRI with perfusion MRI, spectroscopy, or PET for complete evaluation should be developed [15].
In conclusion, results of this study added to the evidence that DW-MRI was a reliable and a clinically important tool for the assessment of brain tumors. It allowed for insights into tumor cellularity, grade and infiltration to be gained, as well as observing treatment response and early signs of recurrence effectively. The introduction of DW-MRI in neuro-oncological imaging management protocols increased the diagnostic precision and decision-making process regarding treatment and ultimately improved patient management. Further work aimed at standardization of ADC thresholds and combination with innovative imaging techniques may lead to further optimization of its utility in the clinical setting.

CONCLUSION:

The study concluded that diffusion-weighted magnetic resonance imaging (DW-MRI) was a useful tool in the assessment of brain tumors and response to treatment. It was observed that DW-MRI gave critical information about tumor cellularity, extent of infiltration, differentiation of tumor recurrence and post-treatment changes. Apparent diffusion coefficient (ADC) values were instrumental in evaluating the aggressiveness of the tumor and tracking therapeutic efficacy in agreement with clinical and radiological response being strongly correlated with ADC changes. DW-MRI was found to be non-invasive, fast and highly reproducible and thus an effective adjunct to traditional MRI sequences. The study was able to show that DW-MRI as part of regular imaging protocol increased the diagnostic accuracy, provided information for the treatment plan and also made it possible to change therapy on time. Overall, DW-MRI has a promising impact on the ability to assess brain tumors and track response to treatment, and thus on the optimal management of patients and outcome in the field of neuro-oncology.

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