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ORIGINAL ARTICLE

Diagnostic accuracy of diffusion weighted magnetic resonance imaging in differentiating benign and malignant meningioma taking histopathology as gold standard.

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ABSTRACT… Objective: To evaluate the ability of diffusion-weighted MR Imaging to distinguish malignant meningiomas from benign, taking histopathology as the gold standard. **Study Design:** Cross-Sectional Validation Study. **Setting:** Department of Radiology, Aziz Fatimah Hospital and Allied Hospital, Faisalabad. **Period:** October 2024 to April 2025. **Methods:** A total of 225 patients aged between 20 to 60 years with suspected meningiomas were enrolled. DWI-MRI was performed using a 1.5 Tesla scanner (b-values 0, 500, and 1000 s/mm²). Findings were interpreted by a consultant radiologist and compared with histopathology. Sensitivity, specificity, positive predictive value, negative predictive value, and diagnostic accuracy were calculated using SPSS version 20.0; a p-value < 0.05 was considered significant. **Results:** DWI-MRI showed a high diagnostic accuracy (86.67%) in distinguishing malignant from benign meningiomas, with sensitivity 88.52%, specificity 84.47%, PPV 87.10% and NPV 86.14% (p = 0.0001). **Conclusion:** DWI-MRI is a reliable, non-invasive imaging modality with high diagnostic accuracy for differentiating benign and malignant meningiomas and can significantly aid in preoperative assessment and treatment planning.

Key words: Diffusion-Weighted Imaging, DWI-MRI, Histopathology, Meningioma, Magnetic Resonance Imaging.

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INTRODUCTION

Meningiomas are the most common type of primary intracranial tumors, contributing to nearly one-fifth of all brain and spinal tumors.[1] Their global incidence is estimated at about 8–10 cases per 100,000 people annually, with frequency increasing with age.[2] Improved availability of neuroimaging and rising life expectancy have contributed to a higher detection rate, and autopsy findings reveal that around 1–2% of the population may harbor small, asymptomatic meningiomas.[3] These tumors typically originate from arachnoid cap cells and are usually located along the cerebral convexities, falx cerebri, and skull base. Intraventricular locations are rare.[4] Meningiomas are most frequently diagnosed in middle-aged individuals and occur more often in females.[5] The highest incidence observed between 45 and 55 years of age, with increasing frequency in the elderly. The average age at diagnosis for posterior fossa meningiomas is reported to be 43.5 years.[6]

The development of meningiomas is strongly associated with genetic alterations, particularly mutations in the NF2 gene, while hormonal influences, especially progesterone sensitivity, also play a role. Prior cranial radiation exposure and inherited conditions such as neurofibromatosis type 2 further increase the risk. Advancing age and female gender are recognized as additional contributing factors.[7]

Clinical presentation depends on tumor size and location. Small meningiomas may remain asymptomatic, whereas larger lesions can cause headaches, seizures, or focal neurological deficits such as weakness, vision problems, or speech disturbances. Cognitive or personality changes may also appear in tumors affecting the frontal lobes.[8]

Most meningiomas are benign, slow-growing masses with well-demarcated borders and broad dural attachments.

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On magnetic resonance imaging (MRI), the "dural tail sign" - a tapering enhancement along the dura adjacent to the tumor - is considered characteristic, being present in 50–70% of cases.[9] Tumors less than 2.5 cm in size are often asymptomatic; however, larger tumors may produce progressive neurological symptoms.[10] Although the majority of meningiomas are benign, around 10% are atypical or malignant. These higher-grade variants demonstrate more aggressive behavior, including bone and parenchymal invasion, and are linked to higher rates of morbidity, mortality, and recurrence of up to 29–41%. Early and accurate distinction between is, therefore, essential for guiding surgical planning, determining the extent of resection, and deciding the need for adjunctive radiotherapy.[11]

According to the World Health Organization (WHO) classification, meningiomas are categorized into Grade I (benign, accounting for 80–85%), Grade II (atypical, about 15–20%), and Grade III (anaplastic/malignant, 1–3%). While Grade I tumors usually have a favorable prognosis, higher grades demonstrate aggressive behavior, higher recurrence rates, and worse clinical outcomes. The Ki-67 proliferation index has been proposed as an additional marker to predict aggressiveness.[12]

From a clinical perspective, the increasing incidence of meningiomas poses a significant healthcare burden due to their long-term follow-up needs, recurrence potential, and surgical demand. With populations living longer, the detection and management of these tumors are expected to rise, highlighting the need for accurate, non-invasive pre-operative grading.[13]

MRI is the foremost diagnostic tool for the detection of suspected meningiomas, significantly enhancing diagnostic accuracy and surgical planning.[14] DWI-MRI is a functional approach that measures water molecule motion at the cellular level and has shown promise in the characterization of brain tumors. Research on gliomas has demonstrated an inverse relationship between ADC values and tumor grade, and comparable trends are now being observed in meningiomas.[15]

Evidence on the diagnostic reliability of DWI-MRI for distinguishing benign from malignant meningiomas is limited, particularly in local settings. This study evaluates its performance against histopathology to determine its reliability as a non-invasive, pre-operative grading tool. If proven accurate, DWI-MRI could be integrated into routine practice to improve surgical planning and reduce complications associated with high-grade tumors.

METHODS

This cross-sectional validation study was conducted at the Radiology Department of Aziz Fatimah Hospital and Allied Hospital, Faisalabad, over a period of six months, from October 2024 to April 2025. Total 225 patients were enrolled. The sample size was calculated using a 95% confidence level, 10% margin of error, and based on an expected prevalence of malignant meningiomas of 23%, with previously reported sensitivity and specificity of DWI-MRI as 84.4% and 82.3%, respectively. Ethical approval was obtained (Ref. no. IEC/417-25) for this study was obtained from the institutional Ethical Committee of Aziz Fatimah Medical and Dental College Faisalabad before initiating data collection, and informed written consent was secured from all participants.

Total 225 patients aged between 20 - 60 years were enrolled, with a symptom duration of more than one month and a lesion size greater than 1 cm on imaging. Exclusion criteria comprised patients with a previously diagnosed meningioma presenting for follow-up, pregnant women, individuals with a known allergy to intravenous contrast, renal dysfunction, and patients who were claustrophobic and unable to undergo MRI.

All subjects underwent 1.5 Tesla MRI system (GE Healthcare Signa HD). DWI-MRI was performed using a single-shot spin-echo echo-planar imaging sequence with TR/TE/NEX of 4200/140 ms/1, and diffusion encoding were carried out by applying gradients in sequence along the X, Y, and Z axes with b-values set at 0, 500, and 1000 s/mm^2. The imaging parameters included a slice thickness (5 mm), interslice gap (1 mm), a FOV (240 mm), and a matrix (128 × 256), with a total acquisition time of approximately 80 seconds. Orthogonal and trace images, and ADC maps, were generated. ADC

values were computed by the MRI software and recorded in 10^{3} mm^2/s, with regions of interest (ROIs) placed both within the lesion and in the contralateral normal brain parenchyma.

MRI findings were interpreted by a consultant radiologist with a minimum of three years of post-fellowship experience. Each lesion was categorized as benign or malignant based on its diffusion characteristics and ADC values. All patients subsequently underwent biopsy or surgical resection, and the histopathological diagnosis was considered the gold standard for comparison. Demographic and clinical data, along with imaging and histopathological findings, were recorded on a structured proforma for analysis. Data analysis was performed using SPSS version 20.0. An Independent t-test was applied to compare the mean ADC values between the two groups. A p-value of <0.05 was considered statistically significant at a 95% confidence interval. Diagnostic performance of DWI-MRI was evaluated by determining its specificity, sensitivity, NPV, PPV, and overall diagnostic accuracy through 2×2 contingency tables, taking histopathology as the gold standard.

RESULTS

A total of 225 patients were evaluated, with ages ranging from 20 to 60 years (mean: 45.62 ± 8.75 years). Most of the patients (71.11%) were in the 41– 60 year age group. There were 121 males (53.78%) and 104 females (46.22%), yielding a male-to-female ratio of 1.2:1. The mean duration of symptoms was 5.23 ± 1.89 months, and the average lesion size was 4.48 ± 1.34 cm. Baseline demographic characteristics are shown in Table-I.

All patients underwent DWI-MRI, followed by histopathological confirmation. Based on 2×2 contingency analysis, DWI-MRI correctly identified 108 malignant cases (true positives), while 87 were true negatives. There were 16 false positives and 14 false negatives. The association was found to be statistically significant (p = 0.0001) and is presented in Table-II.

For distinguishing malignant from benign meningiomas, DWI-MRI demonstrated a sensitivity of 88.52%, specificity of 84.47%, PPV of 87.10%, NPV of 86.14%, and an overall diagnostic accuracy of 86.67%.

TABLE-I.

Baseline characteristics of study population (n = 225)

Variable	Frequency (%) or Mean ± SD
Age (years)	45.62 ± 8.75
20-40	65 (28.89%)
41-60	160 (71.11)
Gender	
Male	121 (53.78%)
Female	104 (46.22%)
Duration of Symptoms	5.23 ± 1.89 months
≤ 6 months	172 (76.44%)
> 6 months	53 (23.55%)
Lesion Size (cm)	4.48 ± 1.34
≤ 5 cm	174 (77.33%)
> 5 cm	51 (22.67%)
Place of Residence	
Rural	109 (48.44%)
Urban	116 (51.56%)

TABLE-II.

Diagnostic Accuracy of DWI-MRI vs. Histopathology

	Histopathology Positive	Histopathology Negative
DWI-MRI Positive	108 (TP)	16 (FP)
DWI-MRI Negative	14 (FN)	87 (TN)
P-value		0.0001

Stratified analysis revealed notable variations in the diagnostic accuracy of DWI-MRI across different subgroups. Male patients demonstrated a higher diagnostic accuracy (91.73%) compared to females (80.77%). Accuracy was also significantly higher among patients with a disease duration of more than six months (98.11%) compared to those with a shorter duration. Similarly, lesions larger than 5 cm yielded slightly higher accuracy (86.27%) than smaller lesions. When evaluated by place of residence, patients from rural areas showed greater diagnostic accuracy (95.41%) than those from urban areas (78.45%). Additionally, patients aged between 41–60 years exhibited a marginally higher diagnostic accuracy (87.50%) compared to those aged 20–40 years (84.62%). These subgroup outcomes are summarized in Table-III.

TABLE-III.

Summary of Stratified Diagnostic Accuracy of DWI-MRI

Variable		Sensitivity	Specificity	Accuracy
Age	20-40 years	78.13%	90.91%	84.62%
	41-60 years	92.22%	81.43%	87.50%
Gender	Male	98.44%	84.21%	91.73%
	Female	77.59%	84.78%	80.77%
Duration	≤ 6 months	83.33%	82.95%	83.14%
	> 6 months	100.00%	93.33%	98.11%
Size	≤ 5 cm	87.25%	86.11%	86.78%
	> 5 cm	95.00%	80.65%	86.27%
Residence	Rural	98.48%	90.70%	95.41%
	Urban	76.79%	80.00%	78.45%

DISCUSSION

Meningiomas rank among the most prevalent benign tumors within the brain and frequently present in the cerebellopontine angle (CPA).[16] Imaging techniques are essential for accurate diagnosis and for surgical intervention.[17] This study aimed to evaluate the effectiveness DWI-MRI in distinguishing malignant meningiomas from benign ones, using histopathological examination as the gold standard. The findings demonstrate that DWI-MRI has high diagnostic performance, with a sensitivity of 88.52%, specificity of 84.47%, and overall accuracy of 86.67%. These results support the growing body of evidence highlighting DWI-MRI as a valuable, non-invasive imaging modality for preoperative evaluation of meningiomas.

Our findings align closely with those reported by Sohu et al., who observed sensitivity and specificity of 84.4% and 82.3%, respectively, for DWI-MRI in grading meningiomas, though these figures are slightly lower than those observed in our study.[18] Similarly, Surov et al., found that the sensitivity, specificity, and diagnostic accuracy of DWI-MRI were 72.9%, 73.1%, and 73.0%, respectively, which are also lower than our findings, possibly due to differing patient populations and MRI protocols.[19] In a 2020 meta-analysis that pooled data from multiple studies, Siempis et al., found the average sensitivity and specificity of DWI in grading meningiomas to be 80% and 76%, respectively, with an area under the ROC curve of 0.91, supporting its clinical relevance.[20] These metrics are in agreement with our results, reinforcing the diagnostic role of DWI in routine neuroimaging protocols.

Our study is also consistent with findings by Sacco et al., where sensitivity ranging from 72.9% to 93.8% and specificity from 64.8% to 97.4%, further confirming the reliability of DWI as a non-invasive diagnostic tool.[21] Similarly, a recent study by Mousam Panigrahi et al., using a threshold-based DWI approach found a sensitivity of 66.7% and specificity of 75% in differentiating benign from malignant meningiomas.[22] Another recent study reported even higher diagnostic performance, with DWI achieving 81.8% sensitivity and 97.4% specificity in differentiating benign from malignant meningiomas. These diagnostic values further support the utility of DWI as a reliable and non-invasive imaging tool in the preoperative assessment of meningioma grade.[23]

In addition, a study by Xiaoyu Huang et al., emphasized that factors such as gender, tumor diameter, peritumoral edema, and ADC_{min} were significantly associated with brain invasion in meningiomas. Their predictive model incorporating these variables achieved an AUC of 0.924, with a sensitivity of 92.2%, indicating excellent diagnostic performance.[24] These findings suggest that combining DWI parameters with clinical and morphological features may further enhance preoperative prediction of aggressive tumor behavior.

In our study, stratified analysis showed higher diagnostic accuracy in male patients, those with lesions larger than 5 cm, and patients with disease duration exceeding six months. These variations may reflect advanced tumor progression, which could present more distinct imaging characteristics on DWI.[25] Interestingly, patients from rural areas demonstrated higher diagnostic accuracy, possibly due to later presentation and more defined pathological changes.[26]

While this study offers valuable insights, it has certain limitations. Being conducted at a single tertiary care center with non-probability sampling restricts the broader applicability of the results. Additionally, inter-observer variability in interpretation was not

assessed. Although our study focused solely on DWI, future research should explore integration with conventional MRI features and multi-sequence analysis. To confirm and enhance the diagnostic value of DWI-MRI in meningioma grading, larger, multicenter prospective studies employing standardized DWI protocols are needed.

CONCLUSION

DWI-MRI demonstrates high sensitivity, specificity, and diagnostic accuracy in differentiating malignant from benign meningiomas when compared with histopathology. Its non-invasive nature, accessibility, and diagnostic performance make it a valuable adjunct for preoperative tumor characterization. Stratified subgroup analysis further supports its utility in varied clinical settings. DWI should be considered a routine imaging tool for meningioma evaluation, especially where biopsy is contraindicated or delayed.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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1	**Shamoona Rashid:** Principal investigator, manuscript writing.
2	**Sadia Zafar:** Data collection.
3	**Syeda Mehwish Zehra:** Data entry.
4	**Hina Rauf:** Data analysis.