Section: Radiodiagnosis

Original Research Article

MAGNETIC RESONANCE CHARACTERIZATION OF MENINGIOMAS AND VALUE OF DIFFUSION WEIGHTED IMAGING IN GRADING OF MENINGIOMAS IN 3TESLA MRI

Sabarinath Eada[1], Venutharla Samson[2], S. Sreenivas[3]

[1,2,3]Assistant Professor, Department of Radiodiagnosis, MNR Medical College and Hospital, Sangareddy, Telangana, India

Received : 10/12/2025
Received in revised form : 28/01/2026
Accepted : 14/02/2026

Corresponding Author:
Dr. Sabarinath Eada,
Assistant Professor, Department of Radiodiagnosis, MNR Medical College and Hospital, Sangareddy, Telangana, India.
Email: sabarinathreddyeada@gmail.com

DOI: 10.70034/ijmedph.2026.1.296

Source of Support: Nil,
Conflict of Interest: None declared

Int J Med Pub Health
2026; 16 (1); 1711-1716

ABSTRACT

Background: Preoperative prediction of meningioma consistency is crucial for surgical planning, as tumor texture influences operative technique, duration, and risk of complications. Conventional MRI provides essential anatomical details but has limited reliability in determining tumor consistency. Diffusion-weighted imaging (DWI) and apparent diffusion coefficient (ADC) measurements may offer additional quantitative insights into tumor microstructure. This study was designed to evaluate the role of conventional MRI and diffusion parameters, particularly normalized ADC (NADC), in predicting the preoperative consistency of intracranial meningiomas and to correlate imaging findings with intraoperative assessment and histopathology.

Materials and Methods: This prospective analytical study included 30 patients with histopathologically confirmed meningiomas who underwent preoperative 3T MRI. Conventional sequences, DWI, and post-contrast imaging were performed. Tumor characteristics, peritumoral edema, edema index, and T2-weighted signal intensity were assessed. ADC values were obtained from solid tumor components, and NADC ratios were calculated using contralateral normal white matter as reference. Imaging findings were compared with intraoperative tumor consistency. Statistical analysis included sensitivity, specificity, and ROC curve evaluation.

Results: Conventional MRI features showed limited predictive value for tumor consistency. T2-weighted signal intensity demonstrated moderate correlation with intraoperative findings. NADC exhibited higher diagnostic accuracy than absolute ADC values, with superior area under the ROC curve. Soft tumors showed high sensitivity, whereas hard tumors demonstrated high specificity on diffusion analysis.

Conclusion: Quantitative diffusion parameters, particularly NADC, improve the preoperative prediction of meningioma consistency beyond conventional MRI features. Incorporation of normalized diffusion metrics into routine imaging protocols may enhance surgical planning and optimize patient outcomes.

Keywords: Meningioma, Magnetic Resonance Imaging, Diffusion-Weighted Imaging, Apparent Diffusion Coefficient, Normalized ADC, Preoperative Assessment.

INTRODUCTION

Meningiomas are the most common primary extra-axial intracranial tumors and constitute a large proportion of adult primary brain neoplasms worldwide, with peak incidence in middle and older age and a marked female predominance. Accurate preoperative characterization of these lesions is essential because tumor location, biological behavior, and mechanical consistency directly influence surgical strategy, risk of complications, and functional outcomes.[1-3]

Conventional magnetic resonance imaging (MRI) remains the imaging backbone for meningioma diagnosis and anatomical delineation. Typical morphologic signs a broad-based dural attachment, homogeneous contrast enhancement, CSF cleft and the dural "tail" help distinguish meningiomas from other extra-axial masses and guide operative planning. However, conventional sequences give limited information about the microstructural composition that determines operative texture (soft, intermediate, hard), and qualitative assessments such as visual T2 signal are observer-dependent and only moderately predictive of actual consistency.[4]

Diffusion-weighted imaging (DWI) and derived apparent diffusion coefficient (ADC) maps quantify water mobility within tissue and have been studied as noninvasive biomarkers of meningioma microstructure. Lower ADC values generally reflect restricted diffusion due to increased cellularity or dense stroma, while higher ADC values suggest increased extracellular space, cystic change, or necrosis. Multiple investigations have demonstrated correlations between ADC metrics and histopathological parameters including tumor grade and proliferation indices (Ki-67) supporting ADC's role in preoperative risk stratification. Nevertheless, firmness in meningiomas often arises from collagenous or calcified stroma rather than cellular packing alone, which can limit the discriminative power of absolute ADC.[5,6]

To address inter-patient and inter-scanner variability and to better reflect relative tissue properties, normalized ADC (NADC) values calculated by dividing tumoral ADC by ADC from contralateral normal white matter have been proposed. Normalization anchors tumoral diffusion to an internal control and has been shown to improve discrimination between softness and firmness, and in some series to enhance differentiation of benign versus atypical/malignant lesions compared with raw ADC values. The added robustness of NADC makes it attractive for routine clinical protocols where equipment and acquisition parameters vary.[6,7]

Peritumoral brain edema, another routinely measured MRI feature, provides complementary information about tumor–brain interface and biological aggressiveness. Extensive edema has been associated with pial blood supply, higher vascular endothelial growth factor (VEGF) expression, and larger tumor burden, and contributes to operative complexity and postoperative management challenges; however, edema extent does not reliably predict intratumoral mechanical texture and therefore should be considered alongside direct tissue measures.[8]

Recent trends toward radiomics and machine-learning aim to combine conventional morphology, diffusion metrics, and higher-order texture features into multivariable models that predict histological grade, molecular subtype, and surgical consistency. Early radiomics studies report encouraging accuracy but face challenges in reproducibility, standardization, and external validation. In the near term, practical, quantitative diffusion measures such as NADC offer an accessible, interpretable improvement over qualitative MRI alone and can be readily integrated into preoperative workflows.[9]

Given ongoing heterogeneity in reported thresholds and methods, prospective studies using standardized high-field MRI protocols, rigorous ROI sampling for ADC/NADC, and blinded intraoperative correlation are needed to refine cutoffs and validate clinical utility. The current study therefore evaluates conventional MRI features, ADC and NADC metrics, and edema indices against blinded intraoperative consistency assessment in a well-characterized cohort of histopathologically confirmed meningiomas, with the aim of identifying robust, clinically applicable MRI markers to guide surgical planning.

MATERIALS AND METHODS

This prospective analytical observational study on patients diagnosed with meningiomas on MR imaging was conducted in Department of Radiodiagnosis at MNR Medical College and Hospital during September 2024 to December 2025. A total of 30 cases with meningiomas diagnosed post-surgical excision on histo-pathology who had undergone pre-operative MRI of the brain were included. Non cooperative patients, pediatric age group, pregnant women, patients with cochlear implants or pacemakers or aneurysmal clips, meningiomas have been treated with surgery, radiation, or chemotherapy within the last six months, patients who have undergone craniotomy for other pathologies within the last one month and cases not willing to participate were excluded. Written informed consent was obtained from all the participants and study protocol was approved by the institutional ethics committee.

Demographic details, clinical presentation, and examination findings were recorded using a structured proforma.

MRI Technique and Imaging Protocol

All MRI examinations were performed using a 3 Tesla scanner (GE Discovery 750W). Patients were screened for ferromagnetic materials and scanned in the supine position using a standard head coil with proper immobilization. The imaging protocol included T1-weighted (T1W), T2-weighted (T2W) axial and coronal planes, FLAIR, 3D FSPGR BRAVO (thin sections), Diffusion-weighted imaging (DWI) with ADC maps, Susceptibility-weighted imaging (SWI) and Post-contrast T1W sequences (axial, sagittal, coronal). Intravenous gadolinium-based contrast was administered at 0.1 mg/kg. Imaging was completed within one hour of contrast injection.

Lesion characteristics assessed included location, size, peritumoral edema, bone involvement, and signal characteristics. Tumor and edema volumes were calculated using maximum orthogonal diameters. The edema index was derived as:

Edema Index = (Volume of edema – Tumor volume) / Tumor volume

Peritumoral edema was graded into three levels (0-2).

Prediction of Surgical Consistency

Tumor consistency was predicted preoperatively based on predominant T2W signal intensity:

T2W Signal Intensity	Predicted Consistency
Hypointense	Hard/Fibrous
Isointense	Intermediate
Hyperintense	Soft

Surgical consistency (gold standard) was determined intraoperatively based on the primary instrument required to remove >80% of the tumor. Radiological and surgical/histopathological assessments were performed independently with blinding.

Diffusion Analysis

DWI was acquired using echo-planar imaging (b = 0 and 1000 s/mm²). Apparent diffusion coefficient (ADC) values were measured by placing four regions of interest (0.2-0.3 cm²) in solid tumor components, avoiding cystic or calcified areas.

Control ADC values were obtained from contralateral normal-appearing white matter.

Normalized ADC (NADC) was calculated as:

NADC = Mean Tumoral ADC / ADC of Normal White Matter

Histopathological Examination

Formalin-fixed, paraffin-embedded specimens were stained with haematoxylin and eosin. Histopathological subtype and WHO grade were confirmed and used as reference standards.

Statistical Analysis: The collected data was extracted to Microsoft Excel sheet and analysed using SPSS v.26.0. Descriptive statistics were expressed as mean ± standard deviation (SD) for continuous variables and frequency (%) for categorical variables. Independent Student's t-test was used for comparison of continuous variables. Chi-square test or Fisher's exact test was used for categorical variables. Receiver Operating Characteristic (ROC) curve analysis was performed to determine diagnostic predictability. A p-value <0.05 was considered statistically significant.

RESULTS

Table 1: Demographic and clinical profile of study participants.

Demographic data	Group A (N=19)	Group B (N=11)
	Number (%)	Number (%)
Age (In years)		
<40	2 (6.6%)	
41-60	16 (53.33%)	
61-80	11 (36.67%)	
>80	01 (3.3%)	
Gender		
Male	5 (26.31%)	7 (63.63%)
Female	14 (73.68%)	4 (36.36%)
Clinical presentation		
Headache	10 (28.6%)	
Weakness	7 (20%)	
Seizures	4 (11.4%)	
Giddiness	3 (8.6%)	
Visual Disturbances	2 (5.7%)	
Scalp swelling	2 (5.7%)	
Others	7 (20%)	

Table 2: Profile of meningiomas

Details of meningiomas	Group A (N=19)	Group B (N=11)
	Number (%)	Number (%)
Location of meningiomas		
Non skull base	13(68.42%)	7(63.6%)
Skull base	6(31.57%)	4(36.4%)
Size of meningiomas		
Small (< 3 cm)	3(15.7%)	-
Intermediate (3-6 cm)	14(73.68%)	9(81.8%)
Large (>6cm)	2(10.5%)	2(18.2%)
Tumor volume		
<20 cm2	9(47.36%)	-
20-50 cm2	6(31.5%)	5(45.5%)
>50 cm2	4(21.05%)	6(54.5%)

Table 3: Imaging features of meningiomas on conventional MRI

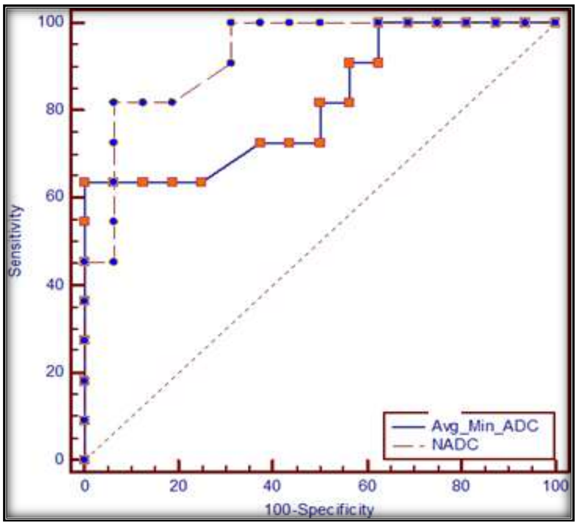
Imaging features	Group A (N=19) Number (%)	Group B (N=11) Number (%)	p-value
Tumor margins			
Ill-defined	4(21.05%)	1(9.1%)	0.0624
Well-defined	15(78.9%)	10(90.9)	
Intratumoral Hemorrhage			
Absent	14(73.68)	7(63.6%)	0.675
Present	5(26.3%)	4(36.4%)	
Intratumoral calcification			
Absent	15(78.94%))	8(72.7%)	0.662
Present	4(21.05%)	3(27.3%)	
Flow void			
Absent	16(84.2%)	8(72.7%)	0.370
Present	3(15.7%)	3(27.3%)	
CSF cleft			
Absent	0(0%)	0(0%)	0.407
Present	19(100%)	11(100%)	
Dural Tail			
Absent	0(0%)	1(9.1%)	0.407
Present	19(100%)	10(90.9%)	
Tumoral cysts			
Absent	17 (89.4%)	11(100%)	1.000
Present	2(10.5%)	0(100%)	
Bony involvement			
Absent	9(47.36%)	5(45.5%)	1.000
Present	10(52.63%)	6(54.5%)	

Table 4: Edema volume, index, and level in the study groups.

Details of meningiomas	Group A (N=19) Number (%)	Group B (N=11) Number (%)
Edema volume		
<40	10(52.6%)	4(36.4%)
40-80	6(31.5%)	4(36.4%)
>80	3(15.7%)	3(27.3%)
Edema index		
<1	11(57.89%)	6(54.5%)
1-4	5(26.3%)	3(27.3%)
>4	3(15.7%)	2(18.2%)
Edema Level		
0	7(36.8%)	2(18.2%)
1	9(47.3%)	5(45.5%)
2	3(15.7%)	4(36.4%)

Table 5: Sensitivity, Specificity, PPV, and NPV in Predicting preoperative consistency on MRI.

Predicting	Sensitivity	Specificity	PPV	NPV
Soft tumors	100%	55%	43.8%	100%
Intermediate tumors	47%	90%	88.9%	50%
Hard tumors	66.7%	100%	100%	96%



Graph 1: ROC curve of ADC and NADC.

Based on the area under the curve, the NADC was slightly better than ADC (0.818), with a value of 0.926. NADC values were also found to be more sensitive than ADC values.

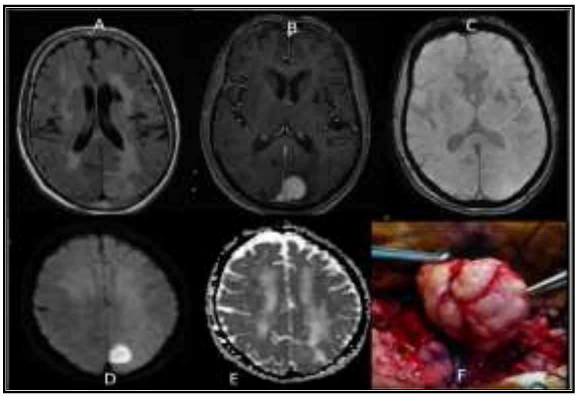


Figure 1: (A) Axial FLAIR image shows a left posterior falcine extra-axial lesion, which appears hyperintense on FLAIR. Mild surrounding white matter tract edema is noted (level1) B) On post-contrast, axial T1WI homogenous enhancement is noted. (C) Axial SWI images show no areas of blooming within. (D) On DWI, significant diffusion restriction is noted; (E) On ADC maps, the average tumoral ADC was found to be 631 x 10-6 mm2/sec, and NADC calculated was found to be1.08. (F) The tumor was found to be intermediate in consistency intra- operatively.

DISCUSSION

The present study findings demonstrate that normalized apparent diffusion coefficient (NADC) values were superior to absolute ADC values in predicting tumor consistency, and that conventional MRI features alone were insufficient to reliably differentiate tumor subgroups. Meningiomas represent the most common extra-axial intracranial tumors, accounting for nearly 30–37% of all primary brain neoplasms.[1] They are more prevalent in females, particularly in the fifth and sixth decades of life, likely due to hormonal influences.[1,10] In our study, the majority of patients belonged to the 41–60-year age group, and a female predominance was observed in Group A, which aligns with previously reported epidemiological trends.[10] Whittle et al. described a similar demographic distribution, emphasizing the female preponderance and middle-aged predominance of meningiomas.[1]

Clinically, headache was the most common presenting symptom in our cohort, followed by focal neurological deficits and seizures. These findings correspond with prior literature indicating that symptomatology depends largely on tumor location, size, and associated mass effect.[11] Non–skull base meningiomas were more common in both groups in our study, consistent with the observation that convexity and parasagittal locations are frequent sites.[12]

On conventional MRI, most tumors demonstrated well-defined margins, dural tail sign, and CSF cleft sign. The dural tail sign, although highly suggestive of meningioma, is not pathognomonic and may be observed in other extra-axial lesions. Goldsher et al. reported that the dural tail is present in approximately 60–72% of meningiomas and correlates with tumor vascularity and reactive dural thickening rather than direct invasion.[13] In our study, dural tail was observed in nearly all cases, reinforcing its diagnostic utility.

Intratumoral calcification and hemorrhage were observed in a subset of patients without statistically significant intergroup differences. Calcification is more frequently associated with fibrous or transitional subtypes and often correlates with firmer tumor consistency.[14] However, in our cohort, conventional imaging features such as calcification, hemorrhage, flow voids, and bony involvement did not significantly differentiate tumor groups, highlighting the limitations of morphological MRI parameters in predicting consistency.

Peritumoral edema is an important factor influencing surgical difficulty and postoperative outcome. We calculated edema volume and edema index, observing variable distribution between groups. Several studies have demonstrated that extensive peritumoral edema correlates with tumor vascular endothelial growth factor (VEGF) expression, pial blood supply, and higher WHO grade.[15,16] Bitzer et al. suggested that larger tumors and aggressive histological subtypes tend to exhibit more pronounced edema.[15] Although our study demonstrated variation in edema levels, edema index alone was insufficient to conclusively predict tumor consistency, supporting previous observations that edema reflects biological behavior rather than mechanical texture.[16]

The principal objective of this study was to evaluate the predictive role of T2-weighted signal intensity and diffusion metrics in determining surgical consistency. Conventionally, hypointense T2 signal has been associated with fibrous, collagen-rich, and hard meningiomas, whereas hyperintense lesions tend to be softer and more cellular.[17] Yamaguchi et al. demonstrated that T2 hypointensity correlates with increased collagen content and firm consistency.[17] In our study, visual T2 assessment showed moderate predictive value, particularly for hard tumors, but lacked adequate sensitivity for intermediate subtypes.

Diffusion-weighted imaging has emerged as a valuable tool in tumor characterization. ADC values inversely correlate with tumor cellularity and extracellular space.[4] Lower ADC values typically reflect higher cellular density and restricted diffusion. However, in meningiomas, consistency is influenced not only by cellularity but also by collagen and fibrous components.[5] This explains why absolute ADC values may not consistently differentiate tumor subtypes.

In our study, ROC analysis revealed that NADC (AUC=0.926) performed better than absolute ADC (AUC = 0.818) in predicting tumor consistency. Normalization to contralateral white matter likely reduces inter-scanner variability and patient-specific diffusion differences. Similar findings were reported by Filippi et al., who demonstrated improved diagnostic accuracy with normalized diffusion ratios compared to absolute ADC values.[4] Furthermore, Nagar et al. showed that ADC ratios provided better discrimination between soft and firm meningiomas than raw ADC measurements.[5]

Our diagnostic performance analysis demonstrated 100% sensitivity for predicting soft tumors and 100% specificity for hard tumors. These findings are clinically significant, as accurate preoperative prediction of tumor consistency aids in surgical planning, selection of instruments, estimation of operative time, and risk stratification. Hard tumors often require more aggressive debulking techniques and may be associated with increased operative duration and blood loss.[18]

The higher AUC for NADC in our study supports the growing consensus that quantitative diffusion metrics enhance preoperative evaluation. Advances in MRI techniques, including diffusion tensor imaging and radiomics-based texture analysis, have further improved characterization of meningioma consistency and grade.[8] Radiomic models integrating ADC histogram parameters have shown promising predictive value for histological grade and surgical texture.[8] Although our study did not include advanced radiomics, the strong performance of NADC suggests that even simplified quantitative approaches can significantly improve diagnostic accuracy.

Despite its strengths, the study has certain limitations. The sample size was relatively small (n=30), and subgroup distribution was unequal. Larger multicentric studies are required to validate cutoff values. Additionally, surgical consistency assessment, although considered a gold standard, is partially subjective and dependent on surgeon experience. Future studies incorporating objective biomechanical measurements may improve reliability.

CONCLUSION

Diffusion-weighted MRI, particularly normalized apparent diffusion coefficient (NADC), is a reliable and superior predictor of meningioma consistency compared to conventional MRI features alone. While T2-weighted signal intensity provides useful preliminary information, quantitative diffusion parameters significantly enhance preoperative assessment. NADC showed higher diagnostic accuracy and better sensitivity in differentiating soft, intermediate, and hard tumors. Accurate preoperative prediction of tumor consistency facilitates surgical planning, instrument selection, and operative risk assessment. Incorporating diffusion metrics, especially NADC, into routine MRI protocols may improve surgical outcomes and optimize management strategies in patients with intracranial meningiomas.

REFERENCES

1. Wiemels J, Wrensch M, Claus EB. Epidemiology and etiology of meningioma. J Neurooncol. 2010;99(3):307-314.
2. Ogasawara C, Philbrick BD, Adamson DC. Meningioma: A Review of Epidemiology, Pathology, Diagnosis, Treatment, and Future Directions. Biomedicines. 2021 Mar 21;9(3):319.
3. Whittle IR, Smith C, Navoo P, Collie D. Meningiomas. Lancet. 2004;363(9420):1535–1543. doi:10.1016/S0140-6736(04)16153-9.
4. Filippi CG, Edgar MA, Uluğ AM, et al. Appearance of meningiomas on diffusion-weighted images: correlating diffusion constants with histopathologic findings. AJNR Am J Neuroradiol. 2001;22(1):65-72.
5. Nagar VA, Ye JR, Ng WH, et al. Diffusion-weighted MR imaging: diagnosing atypical or malignant meningiomas and detecting tumor dedifferentiation. AJNR Am J Neuroradiol. 2008;29(6):1147-1152.
6. Surov A, Gottschling S, Mawrin C, et al. Diffusion-weighted imaging in meningioma: prediction of tumor grade and association with histopathological parameters. Transl Oncol. 2015;8(6):517-523.
7. Tang Y, Dundamadappa SK, Thangasamy S, et al. Correlation of apparent diffusion coefficient with Ki-67 proliferation index in grading meningioma. AJR Am J Roentgenol. 2014;202(6):1303-1308.
8. Park YW, Oh J, You SC, et al. Radiomics and machine learning may accurately predict the grade and histological subtype in meningiomas using conventional and diffusion tensor imaging. Eur Radiol. 2019;29(8):4068-4076.
9. Laukamp KR, Shakirin G, Baeßler B, et al. Accuracy of Radiomics-Based Feature Analysis on Multiparametric Magnetic Resonance Images for Noninvasive Meningioma Grading. World Neurosurg. 2019;132:e366-e390.
10. Wiemels J, Wrensch M, Claus EB. Epidemiology and etiology of meningioma. J Neurooncol. 2010;99(3):307–314.
11. Louis DN, Perry A, Wesseling P, et al. The 2021 WHO classification of tumors of the central nervous system. Acta Neuropathol. 2021;142:391–397.
12. Oya S, Kawai K, Nakatomi H, et al. Natural history of intracranial meningiomas. J Neurosurg. 2011;114(5):1250–1256.
13. Goldsher D, Litt AW, Pinto RS, et al. Dural "tail" associated with meningiomas on Gd-DTPA-enhanced MRI. Radiology. 1990;176(2):447–450.
14. Maiuri F, Iaconetta G, de Divitiis O, et al. Intracranial meningiomas: correlations between MR imaging and histology. Eur J Radiol. 1999;31(1):69–75.
15. Bitzer M, Wöckel L, Luft AR, et al. The importance of pial blood supply to the development of peritumoral brain edema in meningiomas. J Neurosurg. 1997;87(3):368–373.
16. Mantle RE, Lach B, Delgado MR, et al. Predicting the presence of peritumoral edema in meningiomas. Neurosurgery. 1999;44(5):1036–1042.
17. Yamaguchi N, Kawase T, Sagoh M, et al. Prediction of consistency of meningiomas by magnetic resonance imaging. J Neurosurg. 1997;86(2):231–235.
18. Kashimura H, Inoue T, Ogasawara K, et al. Prediction of meningioma consistency using MRI T2-weighted imaging. Neurol Med Chir (Tokyo). 2007;47(10):429–433.