Saudi Journal of Radiology
September 2025 4(2), 57-79

Original Article

PROSPECTIVE LONGITUDINAL STUDY TO ASSESS THE DIAGNOSTIC VALUE OF THE PRE-OPERATIVE BRAIN IMAGES IN PREDICTING THE HISTOPATHOLOGICAL GRADING OF MENINGIOMA

Mohammed Awad Elzain[1], Naeema Abdelaziz Gismelseed[2], Mohammed Hajo Hassan Ibraheim[3], Mohammed Hashim Siddig[4], and Mohamed Eltahir Ali Elrayah[5]

[1 3 4 5] King Saud Medical City, C1 Riyadh Health Cluster, Saudi Arabia

[2] University of South Wales

Received 24 June, 2025
Revised 16 July, 2025
Accepted 23 September, 2025
Published 30 September 2025

Corresponding Author

Mohammed Awad Elzain, King Saud Medical City, C1 Riyadh Health Cluster, Saudi Arabia
Email: alkarsani@yahoo.com

eISSN: 1658-8959

ABSTRACT

Background: Meningiomas are the most common benign intracranial tumors, often exhibiting variable radiological and histopathological features. Accurate preoperative prediction of tumor grade remains a diagnostic challenge, despite advances in imaging.

Objective: To evaluate the correlation between preoperative imaging features and histopathological grading of meningiomas in a retrospective descriptive study.

Methods: This study included 98 patients with surgically managed intracranial meningiomas at King Saud Medical City from December 2022 to December 2023. Preoperative imaging modalities (CT, MRI, MRS, and MR perfusion) were analyzed and correlated with postoperative histopathological grade and subtype.

Results: Most patients were female (59.2%), with a mean age of 50.2 years. On MRI, T2 hyperintensity was observed in 72.4% of tumors and showed a near-significant association with tumor grade ($p = 0.06$). Other imaging features, such as restricted diffusion (59.2%) and peritumoral edema (70.4%), did not show statistically significant correlations with histopathological grading ($p > 0.05$).

Conclusion: Conventional imaging features show limited predictive accuracy for meningioma grading. However, T2 hyperintensity may serve as a potential non-invasive marker. These findings highlight the need for integrating advanced imaging techniques and molecular profiling to improve preoperative tumor characterization and grade prediction.

الملخص

الهدف:

تقييم العلاقة بين خصائص التصوير قبل الجراحة والتصنيف النسيجي المرضي للورم السحائي في دراسة وصفية استعادية.

الطرق:

شملت هذه الدراسة 98 مريضًا خضعوا لجراحة استئصال أورام سحائية داخل الجمجمة في مدينة الملك سعود الطبية خلال الفترة من ديسمبر 2022 إلى ديسمبر 2023. تم تحليل وسائل التصوير قبل الجراحة) الأشعة المقطعيةCT ، التصوير بالرنين المغناطيسيMRI ، الطيف بالرنين المغناطيسيMRS ، والتروية بالرنين المغناطيسي (MR perfusion وربطها بالتصنيف النسيجي المرضي ونوع الورم بعد الجراحة.

النتائج:

كان معظم المرضى من الإناث (59.2%)، بمتوسط عمر 50.2 سنة. أظهر التصوير بالرنين المغناطيسي شدة إشارة عالية في تسلسل T2 لدى 72.4% من الأورام، وقد ارتبط ذلك بشكل قريب من الدلالة الإحصائية مع درجة الورم (p = 0.06). أما السمات الأخرى للتصوير، مثل التقييد في الانتشار (59.2%) والوذمة المحيطة بالورم (70.4%)، فلم تُظهر ارتباطًا ذا دلالة إحصائية مع التصنيف النسيجي المرضي.(p > 0.05)

الاستنتاج:

تُظهر خصائص التصوير التقليدية دقة تنبؤية محدودة في تحديد درجة الأورام السحائية. ومع ذلك، قد تُعد شدة الإشارة العالية في تسلسل T2 مؤشرًا غير غازيًا محتملاً. وتؤكد هذه النتائج على الحاجة إلى دمج تقنيات التصوير المتقدمة والتوصيف الجزيئي من أجل تحسين تقييم الأورام قبل الجراحة والتنبؤ بدرجتها.

Keywords: Meningioma, Histopathology, Tumor Grading, Radiological Correlation, Pre-Operative Brain

1. INTRODUCTION

Meningiomas are among the most common primary intracranial tumors that typically exhibit a broad spectrum of imaging characteristics and histopathological subtypes. Accurate preoperative assessment of tumor grade is crucial for surgical planning and prognostication. While CT and MRI remain essential tools for initial evaluation, their individual features often show variability across different cases and tumor grades.

CT imaging may reveal hypo, iso, hyper density, calcifications, or bony involvement [1] [2], while MRI provides detailed soft tissue contrast and insight into tumor characteristics such as T1/T2 signal intensity, enhancement patterns, and diffusion restriction [3]. However, despite extensive use, the ability of these conventional imaging markers to predict WHO grade remains inconsistent [5]. For example, features like peritumoral edema or bone erosion have been variably linked to atypical or malignant pathology, while advanced tools such as diffusion-weighted imaging (DWI) and MR spectroscopy offer only modest additional value [1]

Research has shown that low-grade meningiomas often have significantly lower apparent diffusion coefficient (ADC) values, particularly in cystic variants, which are considered rare [5] [7]. The reliability of these findings can depend on the type of MRI machine and its field strength [6]. When ADC values are combined with diffusion-weighted imaging (DWI) results, they can enhance the predictive accuracy regarding the histopathological grade of the tumor [7]. Conversely, other MRI sequences, such as T1-weighted imaging (T1WI), T2-weighted imaging (T2WI), and fluid-attenuated inversion recovery (FLAIR), may show lower correlation with histopathological grading [8]. However, reduced FLAIR signal intensity may correlate directly with tumor hardness and vascularity [9].

MRS provides insights into tumor growth rates and proliferative indices but does not directly correlate with histopathological grading [1]. Nevertheless, the predictive efficiency for histopathological grading can reach up to 87% when MRI findings are interpreted in conjunction with MRS data [10]. Notably, cystic rhabdoid meningiomas can mimic glioblastomas radiologically, necessitating histopathological evaluation for accurate diagnosis [11]. Advanced imaging techniques, such as MR SPECT with technetium-99m (Tc-99m), may aid in differentiation [12]. Furthermore, DWI and ADC mapping play significant roles in predicting the aggressiveness and atypical behavior of meningiomas, which may indirectly suggest histopathological grading [13] [14].

Meningiomas may also occur in atypical locations and demographics, complicating their radiological diagnosis; examples include meningiomas in the pineal region of young children [15] and solid intracavernous meningiomas [16] Although most meningiomas are classified as low-grade (WHO Grade I), studies by Gihr et al. have demonstrated a method for predicting higher-grade meningiomas radiologically through ADC profiling, which is significantly lower in high-grade variants and may correlate with progesterone receptor expression and the Ki-67 proliferation index [6].

Additionally, certain intracranial tumors can mimic meningiomas radiologically, including necrotizing sarcoidosis,[17] aspergillomas, [18] and metastatic lesions [19].

A 2024 meta-analysis and systematic review involved 24 studies found that cystic meningiomas demonstrated the highest specificity for predicting low-grade meningiomas, with values reaching up to 93.4%. In contrast, high-grade meningiomas were more reliably predicted by the presence of an irregular brain–tumor interface and heterogeneous contrast enhancement on imaging [23].

With ongoing advancements in imaging technology, standardized data protocols, and enhanced multicenter collaboration, radiomics can be more effectively utilized for early diagnosis, optimized treatment planning, and accurate prognostication of meningiomas. Radiomics offers substantial benefits in the preoperative assessment and management of meningiomas. First, it enables prediction of tumor consistency by analyzing MRI texture and signal characteristics, which is vital for anticipating surgical difficulty and planning the operative approach. Second, radiomic features can help evaluate the risk of brain invasion, allowing surgeons to minimize injury to adjacent normal tissue. Third, radiomics provides detailed insight into the spatial relationship between the tumor and critical brain structures, informing the optimal surgical route. Fourth, predictive models based on radiomic data can estimate postoperative outcomes, including recurrence risk and overall prognosis. Collectively, radiomics supports the development of personalized treatment strategies, guiding decisions on surgery, radiotherapy, chemotherapy, or targeted interventions [24]

This study addresses a critical knowledge gap by evaluating the combined diagnostic performance of standard CT and MRI features in predicting histopathological grade, using a retrospective descriptive design. Unlike advanced radiomics-based approaches, our goal is to assess the utility of accessible, routine imaging findings in real-world clinical settings.

2. METHODOLOGY

This retrospective descriptive study was conducted in the Department of Neurosurgery at King Saud Medical City. Institutional ethics approval was obtained under protocol number H1R1-31-Ocy24-01. As the study involved retrospective analysis of anonymized data, the requirement for informed consent was formally waived by the ethics committee.

The study included all patients who underwent surgical resection of intracranial meningiomas between December 2022 and December 2023. Inclusion criteria were:

(1) a confirmed histopathological diagnosis of meningioma,

(2) availability of both preoperative computed tomography (CT) and magnetic resonance imaging (MRI). Patients were excluded if they were operated outside the hospital, had incomplete imaging studies, or had inconclusive or missing histopathological results.

Sample size was estimated using the standard formula:

$$n = \frac{DEFF \times N \times p(1-p)}{d^2/Z^2_{1-\alpha/2} \times (N-1) + p(1-p)}$$

Based on this, the minimum required sample size was calculated to be 170 patients for a 97% confidence level, 139 patients for 95%, and 98 patients for 90%. With 98 patients included in the final analysis, the study achieved statistical power at the 90% confidence level.

Imaging was performed using standardized protocols. MRI scans were acquired on a 3 Tesla scanner, including T1-weighted (TR ≈ 500 ms, TE ≈ 15 ms), T2-weighted (TR ≈ 3500 ms, TE ≈ 100 ms), FLAIR, diffusion-weighted imaging (DWI), and post-contrast T1-weighted sequences. The slice thickness was 5 mm for all sequences. CT brain imaging was conducted with standard protocol parameters: 120 kVp, auto-modulated mAs (typically 200–300), and axial reconstructions with a slice thickness of 5 mm.

All imaging studies were independently reviewed by two board-certified neuroradiologists who were blinded to the histopathological findings. In cases of disagreement, a consensus was reached through a joint review session. Key imaging features were clearly defined prior to analysis. Restricted diffusion was identified as hyperintensity on DWI with corresponding hypointensity on ADC maps. Hyperostosis was defined as focal or diffuse thickening of the skull bone with trabecular expansion seen on CT bone windows. Peritumoral edema was categorized based on the extent of white matter involvement, while enhancement patterns were classified as homogeneous, heterogeneous, or ring-enhancing.

Inter-observer agreement was assessed using Cohen's kappa (κ) statistics. Agreement levels for key features were strong: κ = 0.84 for T2 signal intensity, κ = 0.79 for diffusion restriction, and κ = 0.82 for skull bone changes.

Data analysis was performed using SPSS software (version 20). As this was a descriptive study, no advanced inferential statistics such as chi-square tests, logistic regression, or ROC curve analysis were conducted. The study focused on summarizing patterns and trends rather than establishing predictive models, which would require a larger cohort and higher-powered design.

3. RESULT

3.1 Age Distribution

A total of 98 patients were included in the study, with a mean age of 50.2 years (SD = 13.8, range: 14–82). The most common age group was 51–60 years (27.6%), and the majority were female (59.2%). (see Table 2).

Table 1: The basic statistics of patients' age

In years		
N	Valid	98
	Missing	0
Mean		50.21
Median		50.50
Mode		40
Std. Deviation		13.788
Minimum		14
Maximum		82

Table 2: The distribution of age in groups

		Frequency	Percent	Valid Percent	Cumulative Percent
	10 - 20	1	1.0	1.0	1.0
	21 - 30	5	5.1	5.1	6.1
	31 - 40	21	21.4	21.4	27.6
Valid	41 - 50	23	23.5	23.5	51.0
	51 - 60	27	27.6	27.6	78.6
	above 60	21	21.4	21.4	100.0
	Total	98	100.0	100.0	

3.2 Gender distribution

More than a half were female with male to female ratio is approximately 0.69:1 or 69 males per 100 females. (n=58/98, 59.2%) (Table 3)

Table 3: The gender distribution of participants

		Frequency	Percent	Valid Percent	Cumulative Percent
	Male	40	40.8	40.8	40.8
Valid	Female	58	59.2	59.2	100.0
	Total	98	100.0	100.0	

3.3 CT findings

All patients in this study were initially investigated by CT-Brain, and in almost half of the cases (n=44/98, 44.9%), the meningioma appeared hyperdense. (Table 4) Also, nearly half of the meningiomas were calcified in CT (n=41/98, 41.8%) (Table 5) The overlying bone was normal in most of the cases while few cases showed hyperostosis vs bony erosion. (Table 6). Interestingly, those with eroded overlying bone showed restricted diffusion on MRI (n=12/19, 63.2%). The histopathology report for meningiomas with overlying bony erosion includes a variety of types, with Meningothelial (syncytial) meningioma being the most common type, appearing in 10 out of 19 cases, making up 52.63% of the total.

Anaplastic (malignant) meningioma is the second most frequent, accounting for 21.05% (4 cases). Atypical meningioma follows with 3 occurrences, representing 15.79%. Both Angiomatous (vascular) meningioma and Transitional (mixed) meningioma are the least common, each occurring once and contributing 5.26% to the total. However, this association was not statistically significant (p = 0.285).

Table 4: The CT findings of the meningioma in terms of density.

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Hyperdense	44	44.9	44.9	44.9
	Hypodense	13	13.3	13.3	58.2
	Iso-dense	41	41.8	41.8	100.0
	Total	98	100.0	100.0	

Table 5: The presence of calcification on CT Brain

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	41	41.8	41.8	41.8
	No	57	58.2	58.2	100.0
	Total	98	100.0	100.0	

Table 6: Meningiomas that showed bony erosion in the overlying skull bone

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Normal	65	66.3	66.3	66.3
	Hyperostotic	14	14.3	14.3	80.6
	eroded	19	19.4	19.4	100.0

Total	98	100.0	100.0

3.4 MRI findings

All patients in this study were investigated through MRI prior to surgical intervention. Among the 98 cases, the majority were Hypointense in T1, accounting for 48% of the total. Isointense signals closely follow, representing 43.9%, while only 8.2% were found to be Hyperintense. These findings suggest that most meningiomas in our study appeared hypointense or isointense on T1-weighted MRI. (Table 7) Hyperintense T2 signals were predominant, observed in 72.4% of cases. Isointense signals were noted in 18.4%, while only 9.2% exhibited Hypointense characteristics. The dominance of hyperintensity in T2-weighted imaging aligns with the common presentation of meningiomas as highly vascular tumours with water content. (Table 8) The FLAIR signal analysis reveals that the majority of cases, 62.2%, exhibited a high signal, indicating fluid attenuation or oedema. The remaining 37.8% demonstrated a Low signal. (Table 9) In diffusion-weighted imaging (DWI), Restricted diffusion was observed in 59.2% of cases, suggesting the dense cellular structure of tumours. The remaining 40.8% exhibited Free diffusion, indicating less cellular restriction. (Table 10) The majority of cases, 67.3%, showed a Homogeneous contrast enhancement pattern, while Heterogeneous enhancement was seen in 31.6%. Only 1% of cases displayed a Ring enhancement pattern. (Table 11) Central necrosis was present in 34.7% of the cases, while absent in 65.3%. The presence of central necrosis may indicate higher tumour grade or ischemic changes within the tumour, whereas its absence reflects typical benign characteristics. (Table 12) Only 14.3% of the cases showed the presence of Hemorrhage within the tumour, while the majority, 85.7%, had no hemorrhagic changes. (Table 13) The surrounding peritumoral edema is graded as No oedema, Grade 1 if it is only surrounding the tumour, Grade 2 if it involves less than the whole cerebral hemisphere, and Grade 3 if it involves the whole cerebral hemisphere. Grade 1 oedema was the most common, seen in 33.7% of cases, followed by Grade 2 oedema (24.5%). No oedema was observed in 29.6%, while the least common was Grade 3 oedema, present in 12.2% of cases. (Table 14)

Table 7: T1-Weighted MRI Signal Characteristic

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Hyperintense	8	8.2	8.2	8.2
	Hypointense	47	48.0	48.0	56.1
	Isointense	43	43.9	43.9	100.0
	Total	98	100.0	100.0	

Table 8: T2-Weighted MRI Signal Characteristics

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Hyperintense	71	72.4	72.4	72.4
	Hypointense	9	9.2	9.2	81.6
	Isointense	18	18.4	18.4	100.0
	Total	98	100.0	100.0	

Table 9: FLAIR Signal Characteristics

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	High signal	61	62.2	62.2	62.2
	low signal	37	37.8	37.8	100.0
	Total	98	100.0	100.0	

Table 10: Diffusion-Weighted Imaging (DWI) Characteristics

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Restricted diffusion	58	59.2	59.2	59.2
	Free diffusion	40	40.8	40.8	100.0

	Total	98	100.0	100.0	

Table 11: MRI Enhancement Patterns

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Homogenous	66	67.3	67.3	67.3
	Heterogenous	31	31.6	31.6	99.0
	Ring enhancement	1	1.0	1.0	100.0
	Total	98	100.0	100.0	

Table 12: Presence of Central Necrosis in Tumors

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Present	34	34.7	34.7	34.7
	Absent	64	65.3	65.3	100.0
	Total	98	100.0	100.0	

Table 13: Hemorrhage Within the Tumor

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Present	14	14.3	14.3	14.3
	Absent	84	85.7	85.7	100.0
	Total	98	100.0	100.0	

Table 14: Surrounding Edema Grading in Meningiomas

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	29	29.6	29.6	29.6

	Grade 1	33	33.7	33.7	63.3
	Grade 2	24	24.5	24.5	87.8
	Grade 3	12	12.2	12.2	100.0
	Total	98	100.0	100.0	

3.5 MRI findings

Out of the 98 patients, only 8 (8.2%) underwent MRS, while a significant majority of 90 patients (91.8%) did not have the procedure done. (Table 15) The most common finding was a high choline/creatine (Cho/Cr) ratio, observed in 3 patients (3.1%) 2 of the patients had Meningothelial (syncytial) meningioma while the remaining one had Atypical meningioma. Other findings included a high Cho/Cr ratio combined with high N-acetylaspartate (NAA) in 1 patient (1.0%) who had Anaplastic (malignant) meningioma, a high choline/NAA ratio in 1 patient (1.0%) who had Meningothelial (syncytial) meningioma, increased choline and decreased NAA in 1 patient (1.0%) with Meningothelial (syncytial) meningioma, a low Cho/Cr ratio with high NAA in 1 patient (1.0%) with Fibroblastic (fibrous) meningioma, and low NAA with high lactate and necrosis in 1 patient (1.0%) with Psammomatous meningioma. (Table 16)

Table 15: The frequency and percentage of patients who were investigated through MRS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Done	8	8.2	8.2	8.2
	Not done	90	91.8	91.8	100.0
	Total	98	100.0	100.0	

Table 16: The specific MRS findings among the investigated individuals

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		90	91.8	91.8	91.8
	High Cho/Cr ratio	3	3.1	3.1	94.9

High Cho/Cr ratio and high NAA	1	1.0	1.0	95.9
high choline/NAA ratio	1	1.0	1.0	96.9
increased choline and decreased NAA	1	1.0	1.0	98.0
Low Cho/Cr ratio and high NAA	1	1.0	1.0	99.0
Low NAA, High lactate, with necrosis	1	1.0	1.0	100.0
Total	98	100.0	100.0	

***Abbreviations**:* Cho/Cr = Choline to Creatine ratio; NAA = N-Acetylaspartate; MRS = Magnetic Resonance Spectroscopy: The specific MRS findings among the investigated individuals

3.6 MRI findings

MR perfusion was done in only 5 patients (n=5/98, 5.1%). (Table 17). Three patients showed soft tissue enhancement in CBV (n=3/5, 60%) 2 of them were Meningothelial (syncytial) meningioma while the 3rd case was Transitional (mixed) meningioma. We had 1 patient who showed high rCBV and 1 who showed low rCBV and both of them were with Meningothelial (syncytial) meningioma. (Table 18).

Table 17: The group of patients for whom MR perfusion was done

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Done	8	8.2	8.2	8.2
	Not done	90	91.8	91.8	100.0
	Total	98	100.0	100.0	

Table 18: Perfusion Findings Analysis

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	high rCBV	93	94.9	94.9	94.9
	Low rCBV	1	1.0	1.0	95.9
	soft tissue enhan -cement in CBV	1	1.0	1.0	96.9
	Total	3	3.1	3.1	100.0
	high rCBV	98	100.0	100.0	

***Abbreviations**:* rCBV = Relative Cerebral Blood Volume; CBV = Cerebral Blood Volume

3.7 Other MRI findings

The most frequent finding was vasogenic edema, which accounted for 69 cases (70.4%). Out of these 69 cases, 33 cases (47.8%) had Grade 1 edema (only around the tumor). While 24 cases (34.8%) had Grade 2 edema (involving less than the whole hemisphere), and 12 cases (12.2%) had Grade 3 edema involving the whole hemisphere. Other findings were relatively rare, each occurring in only 1 case (1.0%) respectively. These included conditions such as another left posterior temporal meningioma, arachnoid cap, bilateral meningeal enhancement, empty sella (a sign of increased intracranial pressure), feeding meningeal vessel, incidental pituitary microadenoma, invasion of the posterior sagittal sinus, multicystic meningioma with scalp lesions, overlying scalp mass, subarachnoid hemorrhage (SAH), and invasion. Hydrocephalus was observed in 3 cases (3.1%). (Table 19)

Table 19: Comprehensive Analysis of Various Other Findings

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		15	15.3	15.3	15.3
	Another Lt posterior temporal meningioma	1	1.0	1.0	25.5

Arachnoid cap	1	1.0	1.0	26.5
bilateral meningeal enhancement	1	1.0	1.0	27.6
Empty Sella , sign of increase ICP .	1	1.0	1.0	28.6
Feeding meningeal vessel	1	1.0	1.0	29.6
Hydrocephalus	3	3.1	3.1	32.7
Incidental pituitary microadenoma	1	1.0	1.0	33.7
Invading the posterior sagittal sinus	1	1.0	1.0	34.7
invasion	1	1.0	1.0	35.7
Multicystic meningioma with scalp lesions	1	1.0	1.0	36.7
Overlying scalp mass	1	1.0	1.0	37.8
SAH	1	1.0	1.0	38.8
vasogenic odema	69	70.4	70.4	100.0
Total	98	100.0	100.0	

3.8 WHO Grading

The majority of cases, 71 out of 98 (72.4%), were classified as Grade 1. This indicates that Grade 1 is the most prevalent type in this study. 20 cases (20.4%) were classified as Grade 2 while Grade 3 was the least frequent type, with only 7 cases (7.1%). (Table 20)

Table 20: Detailed Analysis of Grade Classifications in a Sample of 60 Cases

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Grade 1	71	72.4	72.4	72.4
	Grade 2	20	20.4	20.4	92.8
	Grade 3	7	7.1	7.1	100.0
	Total	98	100.0	100.0	

3.9 Histopathological type of meningioma

The most frequent finding was Meningothelial (syncytial) meningioma, which accounted for 54 cases (55.10%). Atypical meningioma was the second most common, with 16 cases (16.33%). Fibroblastic (fibrous) meningioma and Psammomatous meningioma each accounted for 6 cases (6.12%). Anaplastic (malignant) meningioma was observed in 7 cases (7.14%). Other findings were relatively rare, each occurring in only a few cases. These included Transitional (mixed) meningioma, Angiomatous (vascular) meningioma, Secretory meningioma, Chordoid meningioma, and Clear cell meningioma. (Table 21).

Table 21: Comprehensive Analysis of Various Meningioma Types

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Meningothelial (syncytial) meningioma	54	55.1	55.1	55.1
	Transitional (mixed) meningioma	2	2.0	2.0	57.1
	Fibroblastic (fibrous) meningioma	6	6.1	6.1	63.3
	Psammomatous meningioma	6	6.1	6.1	69.4
	Angiomatous (vascular) meningioma	2	2.0	2.0	71.4
	Secretory meningioma	1	1.0	1.0	72.4
	Chordoid meningioma	2	2.0	2.0	74.5

Clear cell meningioma	2	2.0	2.0	76.5
Atypical meningioma	16	16.3	16.3	92.9
Anaplastic (malignant) meningioma	7	7.1	7.1	100.0
Total	98	100.0	100.0	

3.10 Histopathological type of meningioma

Upon analyzing the above data to correlate between meningioma type and various findings, including MRI findings, CT findings, MR Perfusion findings, MRS findings, surrounding oedema, hemorrhage within the tumor, central necrosis, and overlying skull bone changes including the p-values for each correlation to determine statistical significance the results were displayed down in (Table 22, Figure.1)

Table 22: P-Values for Correlation between Meningioma Type and Various Features

Feature	P-Value
CT_findings	0.270444
T1_MRI	0.229013
T2_MRI	0.060012
FLAIR	0.265367
DWI	0.417047
Perfusion_findings	0.904949
MRS_findings	0.740484
Surrounding_oedema	0.155961
Hge_within_the_tumor	0.160747

Table 22: P-Values for Correlation between Meningioma Type and Various Features

Feature	P-Value
Central_necrosis	0.596304
Overlying_skull_bone	0.285195

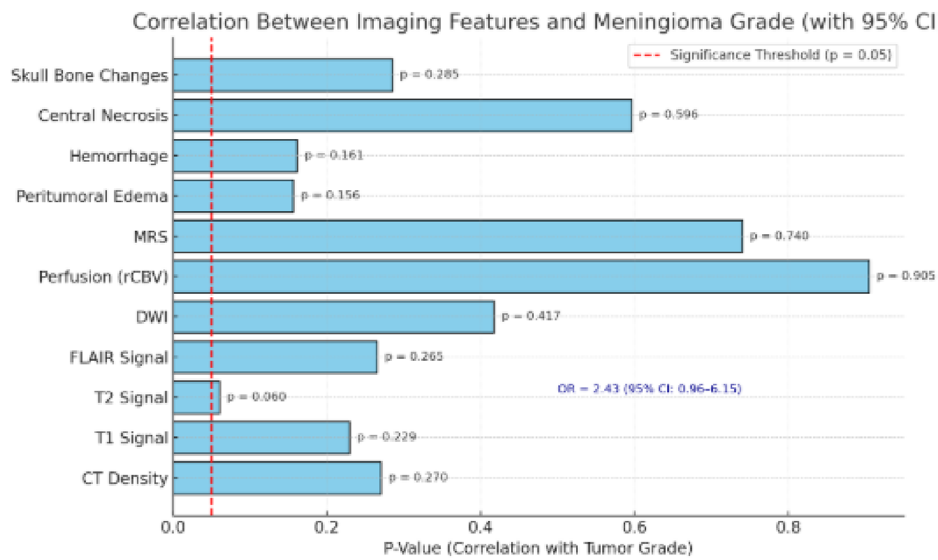

Figure 1: Bar Plot Chart Showing the Correlation between Meningioma Type and Various Features. The red dashed line represents the significance threshold (p = 0.05).

T2_MRI has a p-value of 0.060012, which is close to the significance threshold (0.05), suggesting a potential correlation that may warrant further investigation.

All other features have p-values greater than 0.05, indicating no statistically significant correlation with meningioma type.

Although several imaging features such as bone erosion, edema, and diffusion restriction appeared more frequent in higher-grade tumors, none reached statistical significance except T2 signal, which approached the significance threshold. Multivariate modeling (e.g., logistic regression) was not performed due to sample size limitations but is recommended for future studies to better understand the independent predictive value of combined imaging features.

4. DISCUSION

Meningiomas are considered the most common benign primary brain tumor that vary widely in how they behave clinically, and have wide range of radiological features making their accurate diagnosis and treatment somehow challenging.

Meningiomas are more common in patients over 60, with a noticeable drop in younger patients. These tumors are found mostly in women, Black, and non-Hispanics who are considered at a higher risk when compared to men and White/Hispanic groups, with age being a clear factor in increasing risk.20

This fact is consistent with our study as women made up 59.2% of the cases, with an average age of 50.2 years. This may be explained by the fact that estrogen receptors may play a role in the development of meningiomas. Most of the diagnoses were in patients aged 50-60 years, which could be due to increased incidental findings during routine imaging or symptom-driven evaluations in middle age.

Preoperative imaging is crucial when assessing meningiomas. Amano et al. (2022) found that CT/MRI features such as the tumor's location (away from the skull base), irregular margins, and the presence of peritumoral edema were strongly linked with high-grade histology.21 In our study, we found that hyperdense lesions (44.9%) and calcifications (41.8%) were the 2 common features on CT scans. Interestingly, 63.2% of tumors with bone erosion also showed restricted diffusion on MRI, which may point to more aggressive behavior. However, not all of them were reported as high grade on histopathology reports and the correlation between the malignant behavior of the tumors and histopathology was not statistically significant (p=0.285), This might be due to the limited sample number of the studied population.

Spille et al. (2021) observed that T1-weighted hypointensity (91.8%) and T2/FLAIR hyperintensity (72.4%) were the most common findings, reflecting the tumor's cellular makeup and blood flow. While restricted diffusion (59.2%) tended to correspond with transitional or atypical tumor subtypes. However, the results weren't statistically significant. Besides, Grade 1 tumors often shows peritumoral edema (33.7%), which can make it harder to distinguish them from higher-grade tumors based solely on imaging.22

The principal finding of this study is that conventional imaging features, particularly T2 hyperintensity, demonstrated a near-significant association with higher tumor grade, while most other CT and MRI signs showed limited standalone predictive value. This supports the notion that conventional imaging remains useful for anatomical assessment but is insufficient as a sole predictor of histopathological aggressiveness.

The observed trend toward significance in T2 hyperintensity may be explained by the increased vascularity, intratumoral edema, or higher cellular density, all of which are more frequently seen in atypical or anaplastic meningiomas. This suggests that further research into factors like VEGF (Vascular Endothelial Growth Factor) expression or microvessel density could be valuable. Saito et al. (2021) also found that perfusion MRI metrics were linked to differences in tumor behavior based on location.23

Recent advances in radiomics and perfusion MRI have shown that no single imaging sequence alone—including T2 or DWI—can reliably predict tumor grade. This can be estimated only through multimodal feature integration, including FLAIR, contrast enhancement, CBV maps, and machine learning-based texture analysis.24 These findings echo our results, underscoring the limited diagnostic accuracy of isolated visual signs.

Despite this, the current study highlights a critical gap in practice: the under-utilisation of advanced MRI techniques. Only 8.2% of patients underwent MR spectroscopy, and just 5.1% had perfusion studies. Prospective protocols integrating radiomics, perfusion, and diffusion sequences—ideally interpreted via AI-driven algorithms—may offer significantly higher diagnostic precision and should be prioritized in future research.

This study has several limitations that must be acknowledged. First, the retrospective single-centre design introduces potential selection bias and limits generalizability. Second, the limited availability of advanced imaging modalities, particularly MR spectroscopy and perfusion, restricted our ability to perform more detailed subgroup analyses or predictive modelling. Third, the study lacked assessment of molecular markers such as Ki-67 proliferation index and progesterone receptor (PR) status, which are increasingly recognized as key prognostic indicators. These gaps highlight the need for future prospective, multi-institutional studies incorporating multimodal imaging and molecular profiling to develop robust preoperative predictive frameworks for meningioma grading.

5. CONCLUSION

Conventional imaging features such as CT and standard MRI sequences demonstrate limited accuracy in predicting the histopathological grade of meningiomas. Among these, T2 hyperintensity emerged as a potential ;but not definitive; indicator of higher-grade tumors.

Reliable preoperative grading will require the integration of multimodal imaging techniques, including diffusion, perfusion, and spectroscopy, alongside molecular markers such as Ki-67 and PR status.

Future prospective studies should focus on combining radiologic and genomic data to enhance diagnostic precision and guide personalized treatment.

6. CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

7. FUNDING

The authors did not receive any specific funding for this research.

8. REFERENCES

[1] Chernov MF, Kasuya H, Nakaya K, et al. (1)H-MRS of intracranial meningiomas: What it can add to known clinical and MRI predictors of the histopathological and biological characteristics of the tumor? Clin Neurol Neurosurg. 2011;113:202–12. doi:10.1016/j.clineuro.2010.10.017

[2] Higuchi M, Tsuji M, Fujimoto Y, Ikeda H. Spheno-orbital meningioma with unusual radiological features. Clin Neurol Neurosurg. 1998;100:288–91. doi:10.1016/S0303-8467(98)00050-7

[3] Alyamany M, Alshardan MM, Jamea AA, ElBakry N, Soualmi L, Orz Y. Meningioma consistency: Correlation between magnetic resonance imaging characteristics, operative findings, and histopathological features. Asian J Neurosurg. 2018;13:324–8. doi:10.4103/ajns.AJNS_213_16

[4] Ben-Arie G, Serlin Y, Ivens S, et al. Diagnosing necrotic meningioma: A distinctive imaging pattern in diffusion MRI and MR spectroscopy. Neuroradiol J. 2017;30:57–61. doi:10.1177/1971400916687223

[5] Boukobza M, Cebula H, Pop R, et al. Cystic meningioma: Radiological, histological, and surgical particularities in 43 patients. Acta Neurochir (Wien). 2016;158:1955–64. doi:10.1007/s00701-016-2911-6

[6] Gihr GA, Horvath-Rizea D, Garnov N, et al. Diffusion profiling via a histogram approach distinguishes low-grade from high-grade meningiomas, can reflect the respective proliferative potential and progesterone receptor status. Mol Imaging Biol. 2018;20:632–40. doi:10.1007/s11307-017-1140-8

[7] Chen TY, Lai PH, Ho JT, et al. Magnetic resonance imaging and diffusion-weighted images of cystic meningioma: Correlating with histopathology. Clin Imaging. 2004;28:10–9. doi:10.1016/S0899-7071(03)00125-5

[8] Hadidy AM, Nadi MM, Ahmad TM, et al. Descriptive epidemiological analysis, MRI signals intensity and histopathological correlations of meningiomas. Neurosciences (Riyadh). 2010;15:11–4.

[9] Karthigeyan M, Dhandapani S, Salunke P, Singh P, Radotra BD, Gupta SK. The predictive value of conventional magnetic resonance imaging sequences on operative findings and histopathology of intracranial meningiomas: A prospective study. Neurol India. 2019;67:1439–45. doi:10.4103/0028-3886.273631

[10] Faghih JM, Ghodsi SM, Akhlaghpoor S, et al. Complementary effect of H MRS in diagnosis of suprasellar tumors. Clin Imaging. 2012;36:810–5. doi:10.1016/j.clinimag.2012.02.012

[11] Dutta D, Lee HN, Munshi A, et al. Intracerebral cystic rhabdoid meningioma. J Clin Neurosci. 2009;16:1073–4. doi:10.1016/j.jocn.2008.08.033

[12] Siasios I, Valotassiou V, Kapsalaki E, et al. Magnetic resonance spectroscopy and single-photon emission computed tomography in the evaluation of cerebral tumors: A case report. J Clin Med Res. 2017;9:74–8. doi:10.14740/jocmr2749w

[13] Ranabhat K, Bishokarma S, Agrawal P, et al. Role of MR morphology and diffusion-weighted imaging in the evaluation of meningiomas: Radio-pathologic correlation. JNMA J Nepal Med Assoc. 2019;57:37–44. doi:10.31729/jnma.4226

[14] Sohu DM, Sohail S, Shaikh R. Diagnostic accuracy of diffusion weighted MRI in differentiating benign and malignant meningiomas. Pak J Med Sci. 2019;35:726–30. doi:10.12669/pjms.35.3.176

[15] Gendle C, Karthigeyan M, Salunke P. Pineal region meningioma in a very young child. Pediatr Neurosurg. 2021;56:73–8. doi:10.1159/000512031

[16] Lan Z, Richard SA, Li J, Xu J, You C. A giant solid cavernous hemangioma mimicking sphenoid wing meningioma in an adolescent: A case report. Medicine (Baltimore). 2018;97:e13098. doi:10.1097/MD.0000000000013098

[17] Valappil A, Sundar SS, Johny M, Ahamed TJ. Intracranial necrotising sarcoid granulomatosis mimicking petroclival meningioma. BMJ Case Rep. 2022;15:e250038. doi:10.1136/bcr-2022-250038

[18] Verma R, Singh P, Kumar A, Paliwal VK. Cranial aspergilloma masquerading as meningioma. BMJ Case Rep. 2013;2013:bcr2013200440. doi:10.1136/bcr-2013-200440

[19] Li CZ, Li CC, Lin MC, et al. A clinical pitfall: Optimal management of single dural-based metastatic carcinoma of the breast mimicking meningioma. Neurologist. 2015;20:93–5. doi:10.1097/NRL.0000000000000041

[20] Cao J, Yan W, Li G, Zhan Z, Hong X, Yan H. Incidence and survival of benign, borderline, and malignant meningioma patients in the United States

from 2004 to 2018. Int J Cancer. 2022;151(11):1874–88. doi:10.1002/ijc.34198

[21] Amano T, Nakamizo A, Murata H, et al. Preoperative prediction of intracranial meningioma grade using conventional CT and MRI. Cureus. 2022;14(1):e21610. doi:10.7759/cureus.21610

[22] Spille DC, Adeli A, Sporns PB, et al. Predicting the risk of postoperative recurrence and high-grade histology in patients with intracranial meningiomas using routine preoperative MRI. Neurosurg Rev. 2021;44(2):1109–17. doi:10.1007/s10143-020-01301-7

[23] Upreti T, Dube S, Pareek V, Sinha N, Shankar J. Meningioma grading via diagnostic imaging: A systematic review and meta-analysis. Neuroradiology. 2024;66(8):1301–10. doi:10.1007/s00234-024-03404-0

[24] Song D, Cai R, Lou Y, et al. Advancements in the application of MRI radiomics in meningioma. Radiat Oncol. 2025;20(1):105. doi:10.1186/s13014-025-02679-8