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Correlation between Magnetic Resonance Imaging Characteristics, Operative Findings, and Histopathology of Intracranial Meningioma

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Abstract: Meningiomas are the most common primary intracranial tumors, with surgical resection as the mainstay of treatment. Preoperative prediction of tumor consistency remains a challenge in neurosurgical planning. This study evaluated the correlations among MRI characteristics, intraoperative consistency, and histopathology in intracranial meningiomas. An analytical study was conducted in ninety patients undergoing resection at the National Neurosurgical Referral Centre, NAMS, Bir Hospital, using a convenience sampling method. Preoperative MRI (T1, T2, FLAIR sequences, contrast patterns), intraoperative consistency, and histopathology were recorded. Statistical analysis included chi-square tests and logistic regression (SPSS v26). T2 hypointensity strongly predicted hard tumors (OR=8.9, $p<0.001$), while T2 hyperintensity correlated with soft tumors (71%). FLAIR hypointensity provided additional predictive value (OR=3.2, $p=0.02$). Rim enhancement was highly specific for anaplastic meningiomas. Soft tumors achieved higher Simpson I/II resections (93.8%) compared to hard tumors (58.8%). WHO Grade I tumors had significantly better resection outcomes than Grade III ($p<0.001$). Preoperative MRI, particularly T2-weighted imaging, reliably predicts meningioma consistency and correlates with surgical outcomes, aiding operative planning and patient counselling.

Keywords: *Meningioma, MRI, Tumor consistency, Simpson grade*

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1. Introduction

Meningiomas account for 20–30% of all primary intracranial tumors, predominantly affecting middle-aged adults with 2:1 female predominance (Claus et al., 2005; Dolecek et al., 2012). While most are benign (WHO Grade I), their clinical behavior varies with some demonstrating recurrence and aggressive growth (Jääskeläinen et al., 1986). Surgical resection remains the primary treatment, yet outcomes are influenced by tumour consistency, location, and histopathology (Sheporaitis et al., 1992).

A major challenge is predicting tumor consistency preoperatively, as soft tumors are easily aspirated, whereas fibrous or calcified meningiomas often require sharp dissection, prolonging surgery and risk (Yamaguchi et al., 1997; Carpeggiani et al., 1993). Conventional MRI, particularly T2WI has been studied as a predictor though results are inconsistent (Chen et al., 1992; Hoover et al., 2011). Some studies link T2 hyperintensity to soft tumors while others don't (Maiuri et al., 1999; Elster et al., 1989).

Advances techniques like diffusion-weighted imaging (DWI), fractional anisotropy (FA), and MR elastography show promise (Kashimura et al., 2007; Bano et al., 2013) but are not widely available, especially in resource limited settings. The lack of validated, reliable predictive markers derived from widely available conventional sequences T1, T2, FLAIR that correlate consistently with intraoperative consistency and histopathology remains unaddressed. The correlation between imaging, intraoperative findings, and histopathology requires further validation (Yao et al., 2016; Utomo et al., 2022). This gap limits the ability of neurosurgeons to plan operative strategy without access to advanced imaging.

This study addresses the gap by systematically evaluating the correlations of conventional MRI features with intraoperative consistency and histopathology, aiming to establish reliable predictors to guide surgical planning and improve outcomes.

2. Materials and methods

Review of hospital charts and discharge summaries of all patients who were operated for intracranial meningiomas at National Neurosurgical Referral Centre (NNRC), NAMS, Bir Hospital, Kathmandu, Nepal, from March 2024 to May 2025 was conducted (Reference Number: 1447/2081/82). The study population included all patients undergoing craniotomy for intracranial meningioma resection during the study period, with data were collected following IRB approval. We employed convenience sampling to enroll participants, with inclusion criteria requiring radiological confirmation of meningioma and patient consent for surgical intervention, while excluding recurrent/residual tumors or previously irradiated cases.

Standardized data collection captured three key domains: preoperative MRI characteristics (T1/T2/FLAIR signals, enhancement patterns), intraoperative findings (tumor consistency graded as soft/intermediate/hard based on resection method, instruments used, Simpson grade), and postoperative histopathology. Tumor consistency was classified objectively: Grade I (soft, >80% removable by suction), Grade II (intermediate, requiring CUSA), and Grade III (hard, needing sharp dissection).

Statistical analysis utilized SPSS version 26, employing chi-square tests for categorical variables and logistic regression to identify predictors of hard tumors. All tests used two-tailed significance at $p<0.05$.

3. Results

3.1. MRI Characteristics and Their Correlations

Table 1: MRI signal characteristics across 90 meningioma cases

MRI Sequence	Signal Intensity	n (%)	Consistency	p-value
T1WI	Isointense	47 (52.2)	Intermediate (53%)	0.12
	Hypointense	36 (40)	Hard (61%)	
	Hyperintense	7 (7.8)	Soft (71%)	
T2WI	Hyperintense	42 (46.7)	Soft (71%)	<0.001
	Hypointense	30 (33.3)	Hard (87%)	
	Isointense	18 (20)	Intermediate (55%)	
FLAIR	Hyperintense	68 (75.6)	All groups	0.23
	Hypointense	15 (16.7)	Hard (93%)	
	Suppressed	7 (7.7)	Intermediate (57%)	

Table 1 shows MRI signal patterns in 90 meningioma cases, revealing key predictive relationships: T2-weighted imaging (T2WI) showed the strongest correlation with tumor consistency, where hyperintensity predicted soft tumors (71%) and hypointensity indicated hard tumors (87%) ($p<0.001$). T1-weighted imaging (T1WI) demonstrated no significant association ($p=0.12$), while FLAIR hypointensity was highly specific (93%) but less sensitive for hard tumors. These findings highlight T2WI as the most reliable preoperative predictor of meningioma consistency, with FLAIR providing supplementary value in selected cases.

Table 2: Enhancement patterns vs. tumor subtypes

Enhancement Pattern	n (%)	Tumour Subtype	WHO Grade
Homogeneous	32 (35.6)	Meningothelial (78%)	Grade I (94%)
Heterogeneous	52 (57.8)	Transitional (65%)	Grade I (73%), Grade II (27%)
Rim	6 (6.7)	Anaplastic (100%)	Grade III (100%)

Table 2 shows significant associations between contrast enhancement patterns and meningioma subtypes: homogeneous enhancement predominantly occurred in Grade I meningothelial tumors (78%, 94% Grade I), while heterogeneous enhancement was common in transitional subtypes (65%), with 27% being Grade II. Notably, rim enhancement was exclusively seen in anaplastic (Grade III) meningiomas (100%), making it a highly specific marker for malignant pathology. These patterns provide valuable diagnostic clues for preoperative grading.

Table 3: Multivariate logistic regression for predicting hard tumors

Predictor	Adjusted OR	95% CI	p-value
T2 hypointensity	8.7	3.2-23.1	<0.001
NCCT calcifications	5.2	2.1-12.9	0.001
Heterogeneous T1+C	1.9	0.8-4.3	0.15
Tumor size >4cm	2.4	1.1-5.3	0.03

The multivariate analysis (Table 3) identifies key predictors of hard meningiomas: T2 hypointensity showed the strongest association (OR 8.7, $p<0.001$), followed by NCCT calcifications (OR 5.2, $p=0.001$). Tumor size >4cm was marginally significant (OR 2.4, $p=0.03$), while heterogeneous enhancement showed no significant prediction ($p=0.15$). The model demonstrated good predictive accuracy (AUC 0.87), with T2 signal and calcifications being the most reliable preoperative indicators of tumor hardness.

3.2. Operative Characteristics of Intracranial Meningiomas

Table 4: Tumor consistency and surgical outcomes.

Consistency	Definition	n (%)	Most Common Instruments Used	Simpson Grade I/II (%)	Simpson Grade III/IV (%)	Consistency Grade
Soft (Grade I)	>80% removable by suction	32 (35)	Suction cannula (100%), bipolar (84%)	93.8	6.2	Soft (Grade I)
Intermediate (Grade II)	Mixed suction/CUSA required	41 (45.)	CUSA (100%), bipolar (92%), pituitary forceps (68%)	78.0	22.0	Intermediate (Grade II)
Hard (Grade III)	Required sharp dissection	17 (18.9)	Scalpel (100%), CUSA (100%), monopolar (88%)	58.8	41.2	Hard (Grade III)

Table 4 shows the relationship between tumor consistency and surgical outcomes. Soft tumors (35.6%) were predominantly resectable with suction (93.8% Simpson I/II), while hard tumors (18.9%) required sharp instruments and showed lower complete resection rates (58.8% Simpson I/II). Intermediate tumors (45.6%) typically needed CUSA and had moderate resection success (78% Simpson I/II). The findings highlight how tumor consistency directly impacts surgical approach and resection completeness, with softer tumors yielding better outcomes.

Tumor consistency dictates instrument selection during meningioma resection. Soft tumors (100%) were managed exclusively with a suction cannula, while all hard tumors (100%) required both CUSA and a scalpel. Intermediate tumors showed a transitional pattern, with CUSA used universally (100%) and increasing need for pituitary forceps (68.3%). The highly significant p-values (<0.001) confirm these instrument-consistency relationships are not random, demonstrating how preoperative consistency assessment can guide surgical preparation.

Calcifications showed the strongest association, present in all hard tumors (100%) but rare in soft tumors (6.3%, $p<0.001$). High vascularity was more common in intermediate (51.2%) and hard tumors (52.9%) than soft ones (25%, $p=0.03$). Notably, cystic components appeared exclusively in softer tumors (21.9% soft vs 0% hard, $p=0.04$), while necrosis was absent in soft tumors but present in 23.5% of hard cases ($p=0.01$). These findings demonstrate distinct pathological profiles that correlate with tumor consistency.

Convexity tumors showed the most favorable results highest complete resection rates (85.7% Simpson I/II). In contrast, posterior fossa lesions had the lowest complete resection rates (66.7%). Sphenoid wing tumors exhibited intermediate difficulty. These findings emphasize how anatomical complexity directly affects surgical challenge and success.

3.3. Histopathological Correlations in Intracranial Meningiomas

Grade I tumors (86.7%) showed subtype-specific patterns: meningothelial tumors were typically soft with T2 hyperintensity (59%), while fibrous/psammomatous subtypes were uniformly hard with T2 hypointensity (90-100%). Grade II atypical meningiomas (8.9%) predominantly showed heterogeneous enhancement (88%) and intermediate consistency (75%). Notably, all Grade III anaplastic tumors (4.4%) exhibited rim enhancement, but surprisingly showed variable consistency (50% soft, 50% intermediate). These findings demonstrate consistent radiological-pathological correlations that can aid preoperative planning, particularly in distinguishing benign from higher-grade lesions.

Brain invasion (5.6% of cases) was perfectly predicted by irregular margins and peritumoral edema (100% sensitivity). Calcifications showed excellent diagnostic value, with 100% detection on NCCT and 85% association with T2 hypointensity ($p<0.001$). High mitotic activity (>4/10hpf) was reliably indicated by heterogeneous contrast enhancement (92% sensitivity). Notably, necrosis demonstrated dual imaging correlates - heterogeneous enhancement (89% sensitive) and T2 hyperintensity (67%). These imaging-histology relationships provide valuable preoperative indicators of tumor behavior, particularly for identifying aggressive features like brain invasion or high proliferation. The highly significant p-values (all ≤ 0.003) confirm these are robust, non-random associations that can guide surgical planning and prognostic assessment. Grade I meningiomas showed the best results, with high complete resection rates (84.6% Simpson I/II). In contrast, Grade III tumors had substantially worse outcomes, with only half achieving complete resection (50%). Grade II tumors exhibited intermediate characteristics.

Meningothelial tumors demonstrated the strongest correlation with soft consistency ($r=0.72$) and lowest recurrence (3.1%), characterized by classic whorls and syncytial growth. Fibrous subtypes showed near-perfect association with hard consistency ($r=0.89$) and higher recurrence (10.0%), featuring dense collagen bundles. Transitional tumors exhibited intermediate features both histologically (mixed pattern) and clinically ($r=0.65$, 7.1% recurrence). Higher-grade lesions displayed progressively worse outcomes - atypical meningiomas with increased mitosis had 25.0% recurrence, while anaplastic tumors showed variable consistency but alarmingly high 50.0% recurrence.

3.4. Simpson Grading of Resection

The data reveal a clear inverse relationship between tumor size and resection quality - smaller tumors (3.8±1.2cm) were more frequently completely removed (Grade I, 35.6%), while larger lesions (7.5±0.7cm) typically only permitted decompression (Grade V, 2.2%). Anatomical location significantly influenced outcomes: convexity tumors showed the highest complete resection rates (Grade I/II: 79.5%), whereas challenging skull base locations (petroclival/posterior fossa) accounted for most incomplete resections (Grades IV-V: 8.9% combined). These findings quantitatively demonstrate how both tumor size and location critically determine the extent of achievable resection, with important implications for surgical planning and patient counselling.

Tumor consistency showed the strongest association with resection grade ($p<0.001$), with soft tumors achieving 87.5% Grade I resections, while hard tumors accounted for 70.6% of incomplete (Grade III-V) cases as shown in Table 13. WHO grading significantly impacted outcomes ($p=0.002$), as all Grade I resections involved benign tumors, whereas higher-grade lesions predominated in incomplete resections (52.9%). Vascularity also played a role ($p=0.04$), with high vascularity tumors showing 64.7% incomplete resection rates versus 35.3% for low vascularity cases. These findings demonstrate that soft, low-grade, and less vascular tumors are most amenable to complete resection, while hard, high-grade, or highly vascular lesions pose greater surgical challenges. The data provide valuable prognostic markers for preoperative planning and patient counseling.

Table 5: Multivariate analysis of Grade I/II resection presictors

Factor	Adjusted OR	95% CI	p-value
Convexity location	4.2	1.8-9.7	0.001
Tumor size <4cm	3.8	1.6-8.9	0.002
Soft consistency	12.5	4.3-36.1	<0.001
WHO Grade I	5.6	2.1-14.9	0.001
Low vascularity	2.9	1.3-6.5	0.01

Model accuracy: 84% (AUC=0.89)

As shown in Table 5, the multivariate analysis identifies five key independent predictors of complete meningioma resection (Simpson Grade I/II). Soft consistency showed the strongest effect (OR=12.5, p<0.001), followed by convexity location (OR=4.2) and small tumor size (<4cm, OR=3.8). WHO Grade I histology (OR=5.6) and low vascularity (OR=2.9) were also significant contributors. The model demonstrated excellent predictive accuracy (AUC=0.89), with these factors collectively explaining 84% of resection completeness variability. These results provide a validated, evidence-based framework for preoperative surgical planning - tumors possessing these favorable characteristics (soft, small, convexity-located, low-grade, and less vascular) have a high likelihood of complete resection, while the absence of these features should prompt preparation for more complex procedures and adjuvant therapies.

3.5. T2/FLAIR Correlation with Tumor Consistency

T2-weighted imaging (T2WI) showed particularly strong predictive value (p<0.001), with hyperintensity strongly associated with soft tumors (75%) and hypointensity with hard tumors (76%). FLAIR sequences provided supplementary information (p=0.003), where hypointensity was more common in hard tumors (41%) than soft tumors (3%). The data reveal that T2WI is the most reliable MRI sequence for predicting tumor consistency preoperatively, while FLAIR offers additional, though less definitive, characterization. These imaging-consistency correlations can significantly aid in surgical planning, particularly for anticipating dissection difficulty and selecting appropriate instrumentation.

4. Discussion

The findings of this study demonstrate robust correlations between preoperative MRI characteristics and intraoperative meningioma consistency. T2-weighted imaging emerged as the most reliable predictor, with hypointense signals showing an 8.9-fold increased likelihood of hard tumors (p < 0.001). This aligns with prior research by Yao et al. (2016) and Romani et al. (2014), confirming the T2 signal's reflection of fibrous content. The strong association between T2 hypointensity and difficult resection reinforces its clinical utility for surgical planning, particularly in anticipating the need for ultrasonic aspirators or sharp instruments. This results directly support use of T2WI as a simple, inexpensive and universally accessible predictor of surgical difficulty.

FLAIR sequences provided complementary value, with hypointensity showing moderate but significant association with hard consistency (OR 3.2, p = 0.02). When combined with T2 findings, predictive accuracy improved substantially (AUC 0.93), supporting its adjunctive role in borderline cases. This dual-modality approach addresses limitations noted by Filippi et al. (2001) regarding FLAIR's variable performance across tumor subtypes. The imaging-histopathology correlations were particularly striking for fibrous and psammomatous subtypes, which uniformly demonstrated T2 hypointensity and hard consistency (100% correlation) and thus enhances confidence in using conventional MRI for predicting both surgical behavior and likely tumor subtype.

Enhancement patterns offered critical grading information, with rim enhancement showing high specificity for anaplastic meningiomas. This finding corroborates Utomo et al. (2022) and highlights the importance of contrast administration in preoperative workups. Heterogeneous enhancement predicted intermediate/high-grade tumors with 92% sensitivity, serving as a valuable red flag for atypical histology. These imaging markers enable more accurate surgical planning and patient counselling regarding likely resection completeness and recurrence risks.

The surgical outcome data revealed clinically significant gradients based on resection quality. Simpson Grade I resections showed superior outcomes across all metrics. The multivariate model identified five key predictors of complete resection (AUC 0.89), providing an evidence-based framework for preoperative assessment.

While the study provides actionable clinical insights, certain limitations warrant consideration. The modest sample size of high-grade cases (n = 12) limits subgroup analyses, and longer follow-up would strengthen recurrence data. Future research incorporating advanced sequences like DWI/ADC and perfusion imaging could further refine predictive models, particularly for borderline cases where conventional MRI yields ambiguous results. These findings collectively demonstrate that systematic preoperative MRI analysis can significantly enhance surgical planning and patient management in meningioma care.

5. Conclusion

This study shows that preoperative MRI characteristics—particularly T2 hypointensity—serve as reliable predictors of meningioma consistency, with significant implications for surgical planning. The strong correlation between T2 hypointensity and hard tumors shows its clinical utility in anticipating difficult dissections requiring CUSA or sharp instrumentation. Additionally, FLAIR hypointensity, though less sensitive, provided supplementary value when combined with T2, improving predictive accuracy.

The role of enhancement patterns in preoperative grading is significant, with rim enhancement being pathognomonic for anaplastic meningiomas and heterogeneous enhancement suggesting atypical histology. These imaging markers, along with tumor location and size, significantly influenced resection completeness.

These results advocate for systematic MRI assessment, focusing on T2 signal, FLAIR, and enhancement patterns, to optimize surgical strategy, patient counselling, and postoperative monitoring.

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