Original Article

Meningioma in Focus: Charting the Terrain of Imaging, Grading, and Pathological Vistas

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Abstract

Background: Meningiomas constitute a significant proportion of primary intracranial tumors, demanding a nuanced understanding of their radiological features for informed clinical decisions. This prospective study aimed to explore the intricate relationship between magnetic resonance imaging (MRI) findings and the pathological grade of meningiomas to provide insights into their diverse characteristics.

Materials and Methods: A cohort of 52 meningioma patients underwent comprehensive MRI evaluations. The study encompassed various aspects of tumor radiology, including location, peritumoral edema severity, tumor margin distinctiveness, bone infiltration, adjacent bone reaction, apparent diffusion coefficient (ADC) patterns, intratumoral calcifications, bleeding within the tumor, vascularization, and tumor enhancement.

Results: The analysis revealed that 73.1% of patients presented with grade 1 meningioma, while 26.9% exhibited grade 2 tumors, with no grade 3 cases detected. Intriguingly, while age and gender did not significantly differ between grades, several MRI findings demonstrated noteworthy distinctions. Grade 2 meningiomas were associated with moderate to severe peritumoral edema, indistinct tumor margins, increased vascularization, and heterogeneous tumor enhancement patterns. Notably, logistic regression analysis indicated that none of the investigated radiological parameters independently predicted the pathological grade of meningioma.

Conclusion: These findings emphasize the need for a comprehensive meningioma assessment approach, integrating radiological insights into clinical decision-making and prognosis for enhanced patient care.

Keywords: Meningioma, Pathological grade, MRI findings

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Introduction

Meningioma is the most prevalent primary tumor of the central nervous system (CNS), comprising approximately one-third of all primary tumors affecting the brain and spinal cord[1]. This condition is on the rise[2],

with a noteworthy gender disparity, as the incidence of meningioma in women is reported to be two to three times higher than in men[3]. As the medical community grapples with the increasing burden of this disease, the importance of accurate diagnosis and effective treatment strategies cannot be overstated[4].

In meningioma diagnosis, two pivotal approaches take center stage: imaging and pathology. These diagnostic modalities play distinct yet complementary roles in the comprehensive evaluation of this condition. Imaging techniques, such as Magnetic Resonance Imaging (MRI) and Computed Tomography (CT), provide clinicians with visual representations of the tumor's location, size, and morphological characteristics[5,6]. Conversely, pathology offers an in-depth examination of meningiomas' cellular and histological aspects, allowing for the critical determination of tumor grading according to the WHO classification. This synergistic combination of imaging and pathology empowers healthcare providers with a multifaceted perspective on meningioma cases[7].

However, it is crucial to acknowledge that the compatibility of findings between these two diagnostic modalities is not always guaranteed[8]. The intrinsic variability in how meningiomas present, coupled with the inherent limitations of each diagnostic tool, can occasionally lead to discrepancies in their assessments. These disparities can potentially complicate treatment decisions and, in some cases, may result in suboptimal patient care. Unfortunately, the discordance between imaging and pathology findings remains a relatively unexplored territory in the medical field, and limited data are available to guide clinicians, especially within the Iranian population[9].

Methods

Study Design: This study is a descriptive investigation focused on patients diagnosed with meningioma between 2021 and 2023 at Loghman Hakim Hospital, Shahid Beheshti University of Medical Sciences, Tehran, Iran, who subsequently underwent surgical intervention. The study involves retrospective analysis of patient records and radiological data. Inclusion criteria for study participants include: 1) Having a confirmed histopathological diagnosis of meningioma 2) Patients must have undergone pre-surgery MRI imaging as part of their diagnostic workup. On the other hand, the exclusion criteria include: 1) Meningiomas smaller than 1 cm in size were excluded from the study due to the potential limitations in accurately assessing certain radiological parameters in such cases 2) Patients who did not undergo MRI imaging before their surgical procedure were not included in the study, as their imaging data were essential for the analysis 3) Patients for whom pathology results were unavailable or incomplete were excluded, as these data were crucial for correlating radiological findings with pathological features. 4) Patients who had received chemotherapy or radiotherapy before undergoing MRI imaging were not included, as these treatments could potentially influence the radiological characteristics of the tumor. 5) Patients with MRI images that exhibited significant artifacts, which could impact the accurate assessment of the investigated radiological parameters, were excluded from the study to ensure data quality.

Data Collection: After obtaining approval from the Loghman Hakim Hospital archives and ethics committee, a total of 52 cases of meningioma patients operated on at the hospital during the specified time frame were included in the study. Eligibility criteria for inclusion were histopathological diagnosis of meningioma and the availability of pre-surgery MRI imaging. Exclusion criteria encompassed meningioma size less than 1 cm, absence of pre-surgery MRI, unavailability of pathology results, prior chemotherapy or radiotherapy, and imaging artifacts that could compromise the assessment of relevant parameters.

Imaging: All MRI imaging of the studied patients was performed using a 1.5 Tesla MRI machine. A trained radiologist extracted the following parameters from the MRI scans: tumor volume, peritumoral edema, tumor borders, adjacent bone infiltration, adjacent bone reaction, apparent diffusion coefficient (ADC) appearance, susceptibility-weighted imaging (SWI) features (intra-tumoral calcification, intra-tumoral hemorrhage, tumoral vascularization), and tumoral enhancement.

Tumor Volume Calculation: Tumor volume was calculated using the following formula, where 'l' represents length, 'w' represents width, and

'h' represents height, all extracted from the MRI scans:

$$V = \frac{4}{3} \times \pi \times \frac{l}{2} \times \frac{w}{2} \times \frac{h}{2}$$

Pathological Data: Information related to tumor pathological features, including tumor grade and subtype, was obtained from patient records. Pathologists performed Tumor grading post-surgery using the World Health Organization (WHO) classification system.

Statistical Analysis: The collected data were entered into SPSS version 25 software for analysis. Descriptive statistics such as frequencies and percentages were used to describe qualitative data, while mean and standard deviation were utilized for normally distributed quantitative data. The median and interquartile range were employed in cases where the data did not follow a normal distribution. The chi-square test was applied to compare qualitative imaging results among different meningioma grades. For comparing quantitative characteristics, t-tests were used for normally distributed data, and the Mann-Whitney test was used for non-normally distributed data.

Finally, a multivariate logistic regression analysis was conducted, considering grades one as low-grade and 2 and 3 as high-grade meningiomas to investigate the independent relationships between each radiological parameter and tumor grade. The significance level for the study was set at a p-value of less than 0.05.

Ethical Considerations: This study involved no interventions on patients, imposed no additional costs, and only collected aggregate data for analysis. Patient information was anonymized to protect their privacy. The research proposal received ethical approval from the ethics committee of Shahid Beheshti University of Medical Sciences. (IR.SBMU.MSP.REC.1401.210).

Results

The present study was conducted on 52 meningioma patients with an average age of 55.06 ± 14.34 years (Figure 1). In general, 13 (25.0%) of the studied population were male, and 39 (75.0%) were female. Table 1 presents the radiological findings of the study participants. The distribution of tumors showed variability, with the majority located in supratentorial regions, particularly the convexity-falx area. Peritumoral edema demonstrated a spectrum of severities, with approximately half of the patients experiencing no or minimal edema. Tumor margins varied, with a notable proportion presenting distinct

Table 1: Radiological characteristics of meningioma patients in the study cohort.

Radiology Standard	Results
Tumor Volume (Median (IQR))	32.55 (21.45, 75.84)
Tumor Location (n (%))	Supratentorial (Skull base): 18 (34.6) Supratentorial (Convexity-Falx): 25 (48.1) Supratentorial (Intra-ventricular): 2 (3.8) Infratentorial: 7 (13.5)
Peritumoral Edema (n (%))	Not at all or minimally: 26 (50.0) Medium: 10 (19.2) Intense: 16 (30.8)
Tumor Margin (n (%))	Distinct Margin (Non- Lobulated): 29 (55.8) Distinct Margin (Lobulated): 10 (19.2) Indeterminate Margin (Medium): 3 (5.8) Indeterminate Margin (Wide): 10 (19.2) Without Margin: 35 (76.3)
Adjacent Bone Infiltration (n (%))	17 (32.7)
Adjacent Bone Reaction (n (%))	Without: 30 (57.7) Sclerotic: 22 (42.3)
ADC (n (%))	Iso to Normal White Matter: 17 (32.7) Focal Hypo to Normal White Matter: 2 (3.8) Diffuse Hypo to Normal White Matter: 5 (9.6) Focal Hyper to Normal White Matter: 9 (17.3) Diffuse Hyper to Normal White Matter: 18 (34.6) Heterogeneous (Hypo or Hyper): 1 (1.9)
Calcification Inside the Tumor (n (%))	No Calcification: 33 (63.5) Less than Half of Tumor Volume: 9 (17.3) More than half of Tumor Volume: 10 (19.2)
Bleeding Inside the Tumor (n (%))	No bleeding: 47 (90.4) Focal Point Bleeding: 3 (5.8) Bleeding: 2 (3.8)
Tumoral Vascularization (n (%))	Without Vascularization: 33 (63.5) Medium (Less than Half): 16 (30.8) Wide (More than Half): 3 (5.8)
Tumor Enhancement (n (%))	Homogeneous: 26 (50.0) Heterogeneous: 26 (50.0)

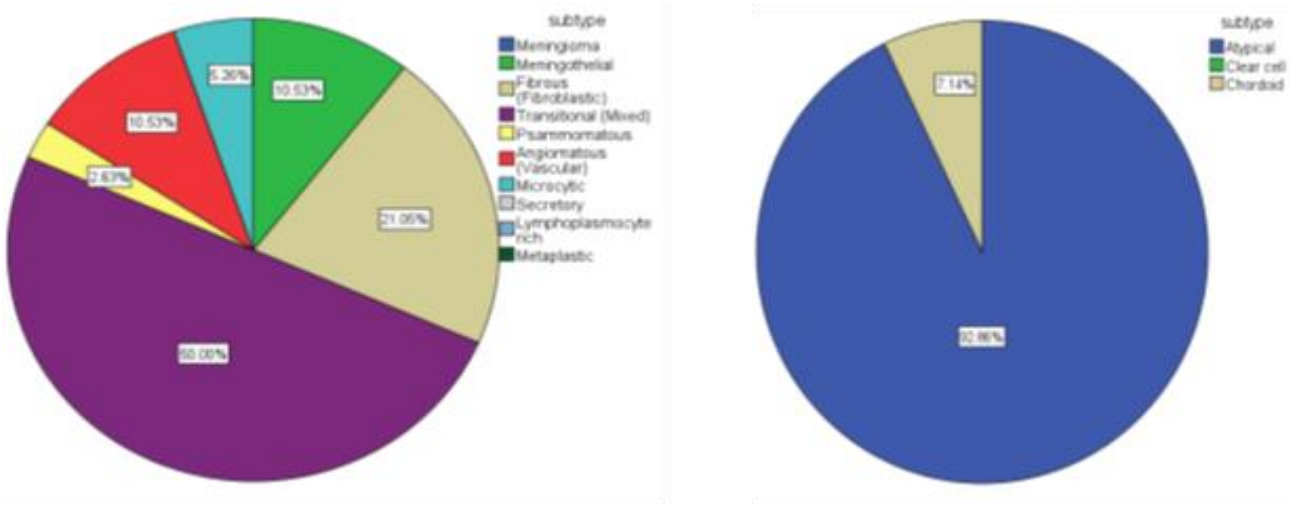

Figure 1. Prevalence of pathological subtypes in Grade 1 (left plot) and Grade2 (right plot) Meningioma Patients

non-lobulated margins. However, there was also a significant subset with indeterminate or ill-defined margins (Figure 1). About one-third of patients exhibited bone infiltration, indicating varying degrees of tumor invasion into surrounding bone structures (Figure 1). Many patients showed a sclerotic reaction in adjacent bone, reflecting a range of responses to the tumor's presence (Figure 1). The ADC appearances were diverse, encompassing a spectrum from iso to normal white matter to focal and diffuse hypo/hyperintensities, indicating tumor tissue heterogeneity. Calcifications, when present, exhibited diversity in terms of volume, with some tumors having extensive calcifications while others had none. The majority of patients had no bleeding within the tumor, but a small subset displayed focal point or more generalized bleeding. Vascularization patterns ranged from none to medium or wide distribution within the tumor, reflecting variations in tumor vasculature. Tumor enhancement showed an even split between homogeneous and heterogeneous patterns, demonstrating the complexity of the enhancement characteristics.

Pathologically, 38 patients (73.1%) were classified as grade 1, while 14 (26.9%) were categorized as grade 2. Notably, no grade 3 tumors were observed within the studied population. Figure 1 illustrates the prevalence of various pathological subtypes of meningioma among participants with grade 1 and 2 tumors in the study. These percentages represent the distribution of pathological subtypes within each group. The subtype of grade 1 with the highest prevalence is Transitional (Mixed) at 36.5%, while Fibrous (Fibroblastic) holds the second position with a prevalence of 21.1%. Most grade 2 meningioma cases belong to the atypical subtype, accounting for 92.7% of all cases within this group, while the remaining cases were classified as choroid subtypes.

Table 2 delineates a comparative analysis of meningioma patients based on their pathological grades (Grade 1 and Grade 2). Several salient observations emerge from this analysis. Age distribution between the two cohorts did not exhibit a statistically significant variance ($p = 0.702$). Likewise, gender distribution was not significantly different between the groups ($p = 0.279$), with both grades comprising a combination of male and female patients. The median tumor volume in Grade 2 patients was marginally elevated compared to Grade 1 patients (37.87 vs. 32.55); to evaluate tumor attributes, this disparity was not statistically significant ($p = 0.837$). An assessment of tumor location did not manifest a significant difference ($p = 0.418$), even though Grade 2 patients presented a higher incidence of infratentorial tumors (15.8%) relative to Grade 1 patients (7.1%). A marked difference was discerned in peritumoral edema between the cohorts ($p = 0.012$), with Grade 2 patients demonstrating a heightened prevalence of moderate edema (78.6%) relative to Grade 1 patients (39.5%). In the context of tumor margins, a significant distinction was evident ($p < 0.001$); Grade 1 patients predominantly exhibited distinct tumor margins (89.5%) in contrast to Grade 2

Table 2: Clinical and radiological characteristics comparison between grade 1 and grade 2 meningioma patients.

Pathological Grade	Grade 1	Grade 2	P-Value
Age (mean ± SD)	55.53 ± 15.05	53.79 ± 12.64	0.70
Gender (n (%))			
Male	8 (21.1%)	5 (35.7%)	0.27
Female	30 (78.9%)	9 (64.3%)	
Tumor Volume (Median, IQR)	32.55 (21.31, 82.30)	37.87 (24.13, 67.71)	0.83
Tumor Location (n (%))			
Supratentorial	32 (84.2%)	13 (92.9%)	0.41
Infratentorial	6 (15.8%)	1 (7.1%)	
Peritumoral Edema (n (%))			
None-Mild	23 (60.5%)	3 (21.4%)	**0.01**
Moderate	15 (39.5%)	11 (78.6%)	
Tumor Margin (n (%))			
Distinct	34 (89.5%)	5 (35.7%)	**<0.001**
Indeterminate	4 (10.5%)	9 (64.3%)	
Adjacent Bone Infiltration (n (%))			
Present	11 (28.9%)	6 (42.9%)	0.34
Absent	27 (71.1%)	8 (57.1%)	
Adjacent Bone Reaction (n (%))			
Present	15 (39.5%)	7 (50.0%)	0.49
Absent	23 (60.5%)	7 (50.0%)	
ADC (n (%))			
Isoogeneous	12 (31.6%)	5 (35.7%)	0.93
Hypoogeneous	5 (14.3%)	2 (14.3%)	
Hyperogeneous	20 (52.6%)	7 (50.0%)	
Heterogeneous	1 (2.6%)	0 (0.0%)	
Calcification Inside the Tumor (n (%))			
Present	15 (39.5%)	4 (28.6%)	0.46
Absent	23 (60.5%)	10 (71.4%)	
Bleeding Inside the Tumor (n)			
Present	3 (7.9%)	2 (14.3%)	0.60
Absent	35 (92.1%)	12 (85.7%)	
Vascularization of Tumor (n (%))			
Absent	29 (76.3%)	4 (28.6%)	**0.002**
Medium to extensive	9 (23.7%)	10 (71.4%)	
Tumor Enhancement (n (%))			
Homogeneous	24 (63.2%)	2 (14.3%)	**0.002**
Heterogeneous	14 (36.8%)	12 (85.7%)	

patients (35.7%). Parameters such as adjacent bone infiltration and adjacent bone reaction did not display significant disparities between the groups ($p = 0.343$ and $p = 0.496$, respectively). ADC characteristics, specifically the distribution of iso, hypo, hyper, or heterogeneous ADC patterns, were analogous between the cohorts ($p = 0.931$). Concerning intratumoral calcification, both groups manifested comparable percentages with no significant difference ($p = 0.469$). Intratumoral bleeding also did not display a significant difference ($p = 0.602$), even though Grade 2 patients exhibited a higher likelihood of bleeding (14.3%) relative to Grade 1 patients (7.9%). A pivotal observation was the significant variance in tumoral vascularization ($p = 0.002$), with Grade 2 patients predominantly displaying medium to extensive

vascularization (71.4%) in contrast to Grade 1 patients (23.7%). Tumor enhancement patterns also revealed a significant distinction (p = 0.002), with a higher propensity for heterogeneous enhancement in Grade 2 patients (85.7%) compared to Grade 1 patients (36.8%). These observations underscore that while age and gender remain consistent across the grades, discernible differences in peritumoral edema, tumor margins, tumoral vascularization, and tumor enhancement patterns exist between Grade 1 and Grade 2 meningioma patients.

In Table 3, we conducted a comprehensive analysis to explore the independent factors influencing the prediction of the pathological grade of meningioma using regression modeling. The model incorporated demographic factors such as age and gender alongside key radiological findings, including peritumoral edema, tumor margin, vascularization, and tumor enhancement. The analysis results reveal an important insight—none of the investigated radiological parameters demonstrated an independent and statistically significant effect on predicting the pathological grade of meningioma. This suggests that, within the scope of this study, these specific imaging findings do not individually contribute significantly to the predictive capacity for meningioma grade.

Discussion

The present study was meticulously designed and executed to delve into the intricate realm of imaging findings among patients diagnosed with meningioma and the potential correlations with the tumor's pathological grade. Among the 52 meningioma patients meticulously examined during this investigation, a substantial portion, precisely 38 cases (73.1%), were classified as pathological grade 1, whereas the remaining 14 cases (26.9%) were attributed to grade 2. Remarkably, this study did not encompass any cases falling under the umbrella of pathological grade 3, emphasizing their rarity within this particular cohort.

Table 3: Predictive factors for meningioma pathological grade. The findings were not significant.

Predictors	95% C.I. (Upper)	95% C.I. (Lower)	Exp. (B)
Age	1.02	0.89	0.95
Gender	3.65	0.10	0.60
Peripheral Edema	17.91	0.31	2.36
Tumor Margin	22.75	0.57	3.62
Vascularization	27.66	0.74	4.55
Tumor Enhancement	34.65	0.63	4.67

Regarding age and gender distribution, our study uncovered no statistically significant disparities between patients falling into grade one and grade two categories. Moving on to the realm of radiological findings, intriguing patterns began to emerge. Factors such as peritumoral edema, tumor margin, heterogenous tumor enhancement, and tumor vascularization displayed statistically significant differences between the grades. Surprisingly, these distinctions did not directly correlate with the ultimate pathological grade of the meningioma.

Notably, the average age of the patients participating in this study stood at 55.06 years, with a notable majority being female, accounting for 75.0% of the cohort. This observation aligns with previous studies that consistently report a higher incidence of meningioma among women, an intriguing phenomenon often attributed to hormonal and genetic variances influencing tumor development[10]. Additionally, 73.1% of the cases under scrutiny in our investigation were identified as pathological grade one, which is congruent with existing epidemiological studies, highlighting that over 80% of meningioma cases worldwide adhere to the grade 1 classification. It is worth noting that our study, conducted within a specialized referral center, may inherently account for this higher percentage of cases classified with a grade 1 status. Notably, neither our study nor previous research endeavors included cases categorized as grade 3, affirming their rarity within the spectrum of meningioma pathologies. Grade 3 meningioma is a seldom-encountered entity, with reported prevalence rates ranging from 1% to 3%, underscoring its exceptional nature within this intricate medical landscape[11].

In the present study, a noteworthy observation emerged, revealing no significant disparity in tumor volume between pathological grades one and two, suggesting a certain degree of uniformity in this regard. Interestingly, this finding diverges from some parallel

investigations where grade 2 cases exhibited a notably higher tumor volume when juxtaposed with their grade 1 counterparts[12-14]. This discrepancy could likely be attributed to variations in the composition of the studied populations across different research endeavors. It is worth emphasizing that our study exclusively scrutinized patients who had undergone surgical procedures, potentially influencing the overall distribution of tumor volumes.

Furthermore, our meticulous examination unearthed another intriguing facet: the prevalence of peripheral edema among grade 2 patients significantly exceeded that in grade 1 meningioma cases. This observation aligns with previous reports in the literature[11,15,16]. However, the etiology of peripheral edema in the context of meningioma remains a subject of ongoing debate. While certain studies have suggested vascular factors, including venous congestion and ischemia stemming from mass growth[17,18], others have not consistently corroborated this hypothesis[19,20]. Additionally, neo angiogenesis, induced by factors such as vascular endothelial growth (VEGF) expression by meningiomas, has been proposed to contribute to peripheral edema[21,22].

Moreover, our investigation revealed a significant increase in vascularization within higher-grade tumors, further accentuating the intricate relationship between pathological grade and tumor vasculature. Non-vascular factors may also play a role in peripheral edema, as evidenced by previous research associating peripheral edema with indeterminate-margin meningiomas[18]. Within our study, peripheral edema, tumor vascularization, and the presence of an indeterminate margin were all notably more prevalent in high-grade tumors than in grade one, potentially reinforcing the interplay between these factors. Intriguingly, despite these intricate relationships, our analysis did not identify any of these factors as possessing an independent and statistically significant effect on tumor grading. In the broader context, peripheral edema has been postulated as a valuable predictor of meningioma grade in numerous studies[23-26].

Meanwhile, our findings on calcification trends revealed intriguing nuances. While some studies have suggested a stronger association between calcification and low-grade tumors [27], our study noted a higher ratio of calcification in grade 1 patients. However, the overall significance of this disparity remains inconclusive. Lastly, our study observed no significant correlation between bleeding within the tumor and the pathological grade, consistent with findings in select prior studies[14].

This study possesses several notable strengths that enhance the reliability of its findings. Firstly, it benefits from a relatively large sample size of 52 meningioma patients, contributing to robust statistical power. The comprehensive evaluation of various radiological parameters, including tumor size, location, infiltration, adjacent bone reactions, ADC values, calcification, bleeding, and tumor enhancement, underscores the study's thoroughness in investigating the potential imaging predictors of meningioma grade. Additionally, the utilization of logistic regression analysis helps elucidate the independent contributions of these factors to pathological grading. Furthermore, the study adheres to a standardized methodology, contributing to its internal validity. However, some limitations must be acknowledged. The study was conducted in a single referral center, potentially introducing selection bias, and may not fully represent the broader population. The absence of grade 3 meningioma cases limits the generalizability of the findings to higher-grade tumors. Moreover, the study's retrospective nature may lead to inherent biases in data collection. Finally, the study's reliance on surgical cases excludes patients managed conservatively, potentially impacting the overall study population's characteristics.

Conclusion

This study investigated the relationship between MRI findings and the pathological grade of meningioma. None of the radiological parameters were examined independently, and the pathological grade was significantly predicted. Age and gender did not differ significantly between the grades, which predominantly included grade 1 (73.1%) and grade 2 (26.9%) meningiomas, with no grade 3 cases. Notably, Transitional (Mixed) and Fibrous (Fibroblastic) were the most prevalent pathological subtypes for grade 1 and 2, respectively, while grade 2 cases were mostly atypical (92.7%). Comparative analysis revealed significant differences between the two grades in peritumoral edema, tumor margin, tumoral

vascularization, and tumor enhancement patterns. Overall, this study highlights the complex nature of meningioma characteristics and underscores the need for a multifaceted approach to grading and diagnosis.

Acknowledgment

None.

Conflict of Interest

The authors further declare that they have no conflict of interest.

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