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Relationship between Edema Index in MRI and Histopathological Grading of Intracranial Meningioma

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Abstract

Background: *Meningiomas are common primary intracranial tumors, classified into three grades and 15 subtypes by the 2016 WHO classification. Though extra-axial, these tumors often show peritumoral brain edema (PTBE). The edema index (EI), from MRI measurements, indicates edema severity. Understanding the relationship between EI and histopathological grading may improve preoperative assessment and treatment planning. This study evaluated the relationship between edema index on MRI and histopathological grading of intracranial meningiomas.*

Methods: *This cross-sectional study included 30 patients with confirmed intracranial meningiomas at Bangladesh Medical University, Dhaka, from September 2022 to October 2024. MRI with contrast determined tumor and FLAIR image determined edema volumes, with EI calculated as (tumor + edema volume)/tumor volume. Data analysis was conducted using SPSS version 26.*

Results: *Participants' mean age was 47.9 ± 11.6 years, with females predominating (76.7%) at a ratio of 3.2:1. Tumors were mainly supratentorial (56.7%), followed by skull base (30%) and infratentorial (13.3%). Among Grade I meningiomas (n=23), 69.6% had EI ≤ 2.0, while 30.4% had EI > 2.0. For Grade II tumors (n=7), 71.4% showed EI > 2.0, indicating more extensive peritumoral edema. Mean EI was significantly higher in Grade II versus Grade I meningiomas (p = 0.0045). A positive correlation between EI and tumor grade suggested that higher edema indices are associated with more aggressive histological features.*

Conclusion: *Higher edema index correlates with increased histopathological grade in intracranial meningiomas, indicating its value as a preoperative radiological marker for surgical planning.*

Keywords: *Meningioma; Edema Index; MRI; Peritumoral Brain Edema; Histopathological Grade*

1. Introduction

Meningiomas are common primary intracranial neoplasms that originate from arachnoid cap cells of the meninges. They ar e typically slow-growing and extra-axial in nature, accounting for approximately 20% of all primary brain tumors in males and up to 38% in females, with an overall favorable prognosis [1].

The female predominance, with an approximate female-to-male ratio of 2:1, has been attributed to hormonal influences, particularly progesterone receptor expression within tumor cells [2].

According to the World Health Organization (WHO) classification, meningiomas are histologically categorized into three grades: Grade I (benign), Grade II (atypical) and Grade III (anaplastic or malignant), representing about 80%, 15–20% and 1–3% of all cases, respectively [3]. Grade I meningiomas are generally well-circumscribed and display indolent biological behavior. In contrast, Grades II and III exhibit increased cellularity, mitotic activity and invasive potential, with higher recurrence rates and poorer clinical outcomes [4]. The distinction between these grades relies primarily on histopathological features such as mitotic index, necrosis and brain invasion [5].

Despite their often-benign nature, peritumoral brain edema (PTBE) is a frequent radiological finding in patients with intracranial meningioma, occurring in approximately 38–67% of cases [3]. The presence of PTBE is of significant clinical relevance, as it may exacerbate neurological symptoms, increase intracranial pressure and complicate surgical resection by causing adhesion to surrounding brain tissue [6]. Moreover, the extent of PTBE has been observed to correlate with tumor aggressiveness, vascularity and histological grade [7, 8]. Higher-grade meningiomas (WHO Grade II and III) are often associated with more extensive edema compared to benign (Grade I) lesions [8].

Several mechanisms have been proposed to explain the development of PTBE in meningiomas, yet none fully elucidate the phenomenon. Among the proposed theories, the hydrodynamic hypothesis is widely accepted. It suggests that plasma filtrates through the abnormally permeable capillaries of the tumor into the surrounding brain parenchyma, leading to vasogenic edema due to altered blood–brain barrier integrity [9]. Additional factors such as tumor size, vascular endothelial growth factor (VEGF) expression and brain–tumor interface characteristics have also been implicated [10].

The Edema Index (EI) has been developed as a quantitative MRI-based parameter to assess the severity of PTBE. It is calculated by dividing the combined volume of the tumor and edema by the tumor volume alone, such that an EI of 1 indicates the absence of edema [11, 12]. Magnetic Resonance Imaging (MRI) remains the most sensitive modality for evaluating intracranial meningiomas, providing essential information regarding tumor morphology, volume and peritumoral changes. MRI findings not only assist in differential diagnosis and surgical planning but may also reflect underlying histopathological features [4].

Preoperative differentiation between benign and higher-grade meningiomas is of critical clinical importance. Accurate prediction of tumor grade can guide surgical strategy, risk assessment and patient counseling. Patients with large or symptomatic tumors, especially those associated with significant PTBE, are typically managed surgically, whereas smaller, asymptomatic lesions may be monitored conservatively [13]. However, intraoperative decision-making often depends on preoperative imaging features that may suggest a more aggressive histopathological profile. Reliable radiological markers, such as EI, could therefore assist in anticipating tumor grade and potential postoperative outcomes [13].

Given the clinical implications of PTBE and its possible correlation with tumor biology, exploring the relationship between the Edema Index on MRI and histopathological grading of meningioma is of substantial relevance. Establishing such an association could enhance preoperative assessment, facilitate more informed surgical planning and improve patient counseling regarding prognosis, risk of recurrence and the need for adjuvant therapy. Moreover, regional data on this relationship, particularly from South Asian populations, remain scarce. This study thus aims to evaluate the relationship between MRI-derived edema index and histopathological grading of intracranial meningiomas, contributing to the growing evidence base on the prognostic value of imaging biomarkers in neuro-oncology.

2. Methodology & Materials

This cross-sectional observational study was conducted in the Department of Neurosurgery, Bangladesh Medical University (BMU), Dhaka, Bangladesh, from September 2022 to October 2024. A total of thirty patients who were clinically and radiologically diagnosed with intracranial meningioma and subsequently underwent surgical excision followed by histopathological confirmation are included in this study.

All eligible patients admitted to the neurosurgery department during the study period were screened according to the inclusion and exclusion criteria. Patients were grouped based on the histopathological grading of their tumors, as determined by the WHO classification (Grade I and Grade II).

2.1. Sample Selection

Inclusion Criteria

- Patients with intracranial meningioma are confirmed by both clinical and radiological findings.
- Patients who underwent surgical resection of the tumor followed by histopathological diagnosis at BMU.
- Patients who provided written informed consent for participation.

Exclusion Criteria

- Recurrent or relapsed meningiomas.
- Presence of other cranial pathologies, including trauma, infection, glioma, or metastasis.
- Multiple or intraventricular meningiomas.
- Poor-quality or incomplete MRI scans are unsuitable for quantitative analysis.

2.2. Data Collection and Study Procedure

All participants underwent a comprehensive clinical evaluation, including detailed history-taking, neurological examination and preoperative MRI of the brain. MRI scans were performed using standard protocols, including T1-weighted contrast-enhanced and FLAIR (Fluid Attenuated Inversion Recovery) sequences.

2.3. Tumor Volume Measurement

Tumor volume was measured on T1-weighted contrast MRI images. The measurements were taken in three orthogonal planes—anteroposterior (A), transverse (B) and craniocaudal (C)—and the volume was calculated using the ellipsoid formula:

$$\frac{AxBxC}{2}$$

Where (A) is the maximum length, (B) is the maximum width perpendicular to (A) and (C) represents the product of slice thickness and the number of slices showing the lesion.

Edema Volume Measurement:

The FLAIR sequence was used to calculate the combined volume of the tumor and surrounding edema using the same geometric formula. The edema volume was determined by subtracting the tumor volume (from T1 contrast images) from the total high-signal volume (tumor plus edema) on FLAIR images.

2.4. Edema Index (EI)

The Edema Index was computed to quantify the degree of peritumoral brain edema using the following ratio:

$$\text{EI}=\frac{VTumor+VEdema}{VTumor}$$

An EI of 1 indicated the absence of oedema, whereas values >1 reflected increasing severity of PTBE.

Image Analysis:

All MRI measurements were conducted using ImageJ software (version 1.53e; National Institutes of Health, USA), a validated image processing program that allows for precise measurement of distances, areas and volumes on radiological images. Each image was independently analyzed by the principal investigator and verified by a senior neuroradiologist to minimize measurement bias.

2.5. Histopathological Grading

Postoperative tissue specimens were examined by pathologists at the Department of Pathology, BMU. Tumors were classified according to the 2016 WHO classification of central nervous system tumors.

Grade I (benign) meningiomas were characterized by low mitotic index (<4 mitoses per 10 high-power fields), absence of brain invasion and fewer than three atypical features (necrosis, small-cell change, sheeted architecture, macronuclei, or hypercellularity).

Grade II (atypical) meningiomas met one major criterion (≥4 mitoses per 10 HPF or brain invasion) or three of five minor criteria (increased cellularity, small cell morphology, prominent nucleoli, sheet-like growth, or necrosis).

All relevant demographic, radiological and histopathological data were recorded using a structured data collection sheet designed and validated by the research team.

2.6. Ethical Considerations

Ethical approval for the study was obtained from the Institutional Review Board (IRB) of Bangladesh Medical University, Dhaka. Written informed consent was obtained from all participants or their legal guardians after explaining the study objectives, procedures, potential risks and benefits in understandable language. Participants were assured of confidentiality and informed that their decision to participate or withdraw would not affect their treatment. Each participant was assigned a unique registration number to ensure anonymity and data were stored securely with restricted access.

The study was conducted in accordance with the Declaration of Helsinki (2013 revision) and adhered to institutional and national research ethics guidelines.

2.7. Statistical Analysis

Data were processed and analyzed using SPSS version 26.0. Quantitative variables were expressed as mean ± standard deviation (SD), while categorical data were presented as frequency and percentage. Comparisons between groups (e.g., Grade I vs. Grade II meningiomas) were performed using the independent (unpaired) t-test for continuous variables and the Chi-square test for categorical variables, where applicable. A p-value <0.05 was considered statistically significant. To assess the association between Edema Index (EI) and histopathological grade, correlation and comparative analyses were performed.

3. Results

Table 1. *Age group distribution of the study patients (n=30)*

Age group (years)	Frequency	Percentage (%)
21-30	2	6.7
31-40	8	26.7
41-50	10	33.3
51-60	6	20.0
61-70	4	13.3
Mean ±SD Median (Range)	47.9 ±11.59	
	47.5 (28, 70)	

Table 1 shows that the age range of patients in this study was 28 to 70 years. The Mean ±SD of age was 47.9±11.59. Most of the patients (33.3%) were between 41 to 50 years range and only 6.7% of the patients were between 21 and 30 years old.

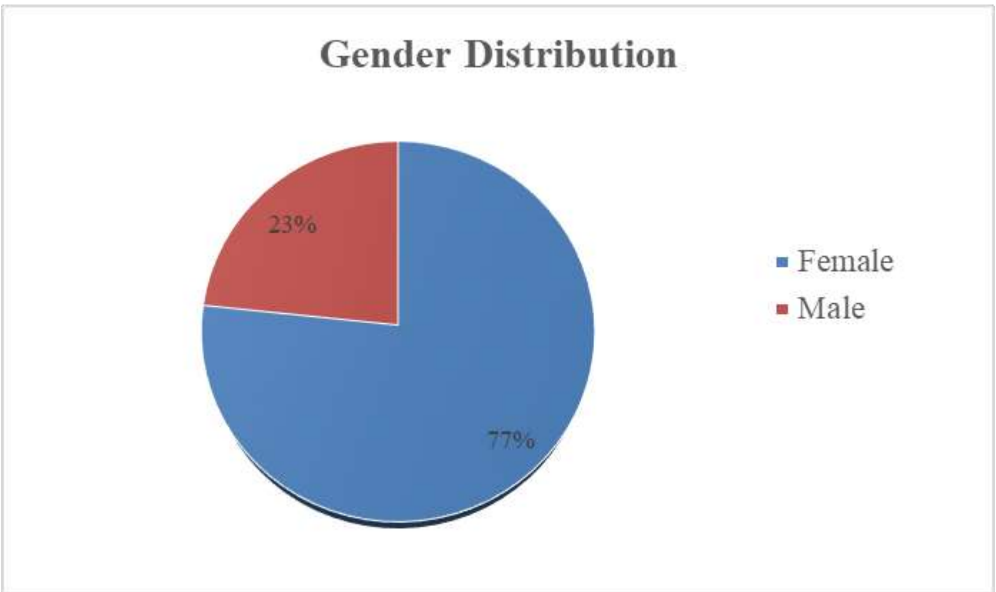

Figure 1. *Pie diagram showing the sex distribution of the study patients (n=30)*

Figure 1 shows that, out of 30 patients, 7 (23.33%) were male and 23 (76.67%) patients were female. The male-female ratio was 1:3.2.

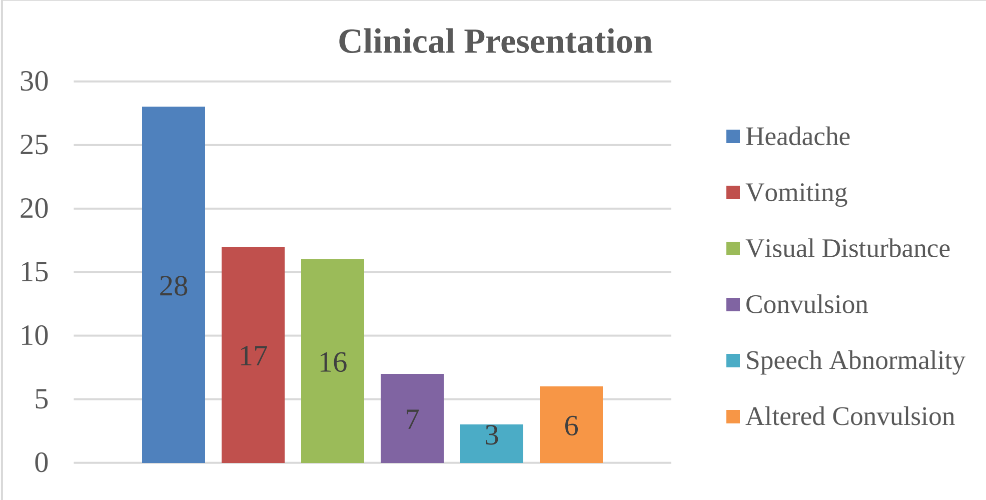

Figure 2. *Bar Diagram Showing clinical presentation of the study patients (n=30)*

Figure 2 above shows the patients according to the clinical presentation. 93.3% of participants had headaches and only 10% of patients had speech abnormalities.

Table 2. *Distribution of the study patients by neurological examination (n=30)*

Neurological Examinations	Present	Absent
Gait Disturbance	11 (36.7%)	19 (63.3%)
Cranial Nerve involvement	18 (60%)	12 (40%)
Motor Deficit	7 (23.3%)	23 (76.7%)
Sensory Deficit	6 (20%)	24 (80%)
Signs of Cerebellar Lesion	4 (13.3%)	26 (86.7%)

Table 2 provides a comprehensive overview of the neurological examination findings in patients with intracranial meningiomas. Gait disturbances were present in 11 patients (36.7%), affecting more than one-third of the cohort. Cranial nerve involvement was the most common neurological finding, presenting in 18 patients (60%). Motor and Sensory deficits were observed in 7 patients (23.3%) and 6 patients (20%), respectively.

Table 3. *Distribution of the study populations by location of tumor (n=30)*

Location of tumor	Frequency	Percentage (%)
Supratentorial	17	56.7
Infratentorial	4	13.3
Skull base	9	30
Total	30	100

Table 3 shows the distribution of the study population by the location of the tumor. In this study, out of 30 patients, 17 patients had tumors that were supratentorial (56.7%), 09 (30%) were skull base and 04 (13.3%) were infratentorial by location.

Table 4. *Distribution of the study populations by histopathological type (n=30)*

Histopathological type	Frequency	Percentage (%)	Grade
Angiomatous	1	3.3	Grade I
Fibrous	3	10	23 (76.7%)
Meningothelial	15	50	
Metaplastic	1	3.3	
Secretory	1	3.3	
Transitional	2	6.7	
Atypical	3	10	Grade II
Chordoid	3	10	7 (23.3%)
Clear cell	1	3.3	
Total	30	100	

Table 4 describes the distribution of the study populations by histological types and grades. Among grade I, Meningothelial was the most prevalent (50.0%), followed by fibrous (10%) and transitional (6.7%). Other types were distributed equally among grade I. Chordoid and atypical are the highest prevalent types (10%) in grade II, followed by clear cell (3.3%).

Table 5. *Distribution of study population by tumor volume and edema volume (n=30)*

Volume	Frequency	Mean ±SD
Tumor volume	30	36.34±22.54
Edema volume	30	33.53±34.38

Table 5 shows the distribution of the study population by tumor volume and edema volume. It shows the mean tumor volume of the participants was 36.34±22.54 cm^3 and the mean edema volume was 33.53±34.38 cm^3

Table 6. *Distribution of patients with Edema Index and histopathological grading*

Edema Index	WHO Histopathological grading	
	I (n=23)	II (n=7)
1	5 (21.73)	0 (0)
1.01-2.0	11 (47.82)	2 (28.57)
2.01-3.0	6 (26.1)	2 (28.57)
3.01-4.0	1 (4.35)	3 (42.86)

Table 6 illustrates the distribution of patients with Edema Index and histopathological grading of meningiomas. It shows that 16 (69.55%) out of 23 patients with Grade I tumors had an edema index within 2.0, while only 7 (30.45%) patients had an edema index more than 2.0. In contrast, only 2 (28.57%) out of 7 patients with grade II had an edema index within 2.0 and 5 (71.43%) patients had an edema index greater than 2.0. This suggests patients with a higher edema index (>2) have a higher possibility of having more aggressive meningioma grades.

A higher edema index reflects more significant peritumoral brain edema, which is often seen in higher-grade meningiomas.

Table 7. *Distribution of Edema Index by histopathological grading*

Group	Sample (n)	Mean ±SD	P value
Grade I	23	1.77±0.62	
Grade II	7	2.78±0.94	0.004538

P-value is reached from the Unpaired T-test

Table 7 shows the Distribution of Edema Index by histopathological grading. The mean edema index in grade I was 1.77±0.62 and in grade II it was 2.78±0.94. P-value was 0.004538, which was statistically significant.

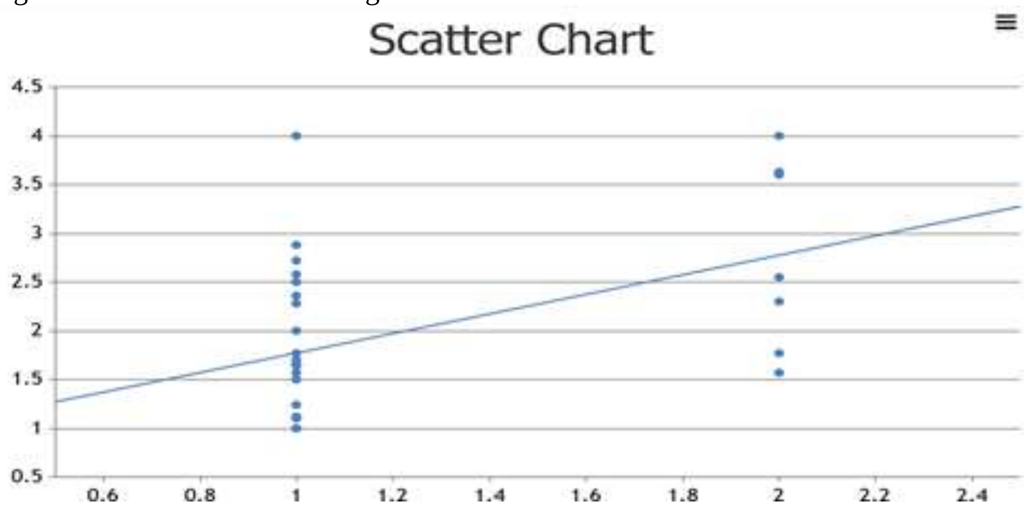

Figure 3: *Scatter diagram showing positive correlation between edema index and histopathological grading of meningioma.*

Figure 3 shows the scatter diagram, showing there is a positive linear correlation between edema index and meningioma grading. Notably, the correlation we found is statistically significant.

4. Discussion

The present study investigated the relationship between the edema index (EI) on MRI and the histopathological grading of intracranial meningiomas. Meningiomas are generally slow-growing, extra-axial neoplasms derived from arachnoid cap cells, comprising a substantial proportion of primary intracranial tumors. Understanding the association between imaging-derived indices and histopathological features is crucial for optimizing preoperative evaluation and prognostication. This study particularly emphasized the Edema Index—a quantitative ratio reflecting the extent of peritumoral brain edema (PTBE) relative to tumor volume—as a potential imaging biomarker for tumor aggressiveness.

The findings demonstrated a statistically significant association between higher EI values and increased histopathological grades. Most patients with Grade II meningiomas exhibited an EI greater than 2, whereas Grade I tumors displayed a broader range of values, typically below this threshold. The unpaired t-test revealed a significant difference in EI between grades ($p = 0.004538$), indicating that a larger peritumoral edema correlates with a higher tumor grade. This pattern aligns with previous reports that established a positive correlation between EI and histological grade. Lee et al. similarly observed a statistically significant relationship ($p = 0.004$) between high EI values and atypical or anaplastic meningiomas [8]. Such congruence across studies reinforces the potential of EI as an auxiliary radiological marker for tumor grading.

The age distribution in the present cohort showed a predominance among middle-aged adults, with a mean age of 47.9 years and the highest incidence in the 41–50-year age group. This observation corresponds to the established epidemiological trend that meningiomas primarily affect individuals in their fifth to seventh decades [1]. The increased incidence among older adults may be related to cumulative genetic mutations, diminished DNA repair capacity and longer exposure to hormonal and environmental risk factors [6].

A female predominance was also evident, with women comprising 76.7% of the cohort and a female-to-male ratio of approximately 3.2:1. This pattern concurs with the findings of Hale et al., who reported nearly threefold higher incidence among women than men [13]. The gender disparity has been attributed to hormonal influences, as many meningiomas express estrogen and progesterone receptors [14]. These hormonal associations suggest a possible endocrine contribution to meningioma pathogenesis and may explain the observed correlation between menopausal status and tumor behavior.

Headache was the most prevalent presenting symptom (93.3%), followed by cranial nerve involvement (60%), motor and sensory deficits (23.3% and 20%, respectively) and seizures (23.3%). These manifestations are consistent with Moradi et al., who identified headache (66.7%) and seizures (28.5%) as common presentations among 378 meningioma cases [2]. The higher frequency of cranial nerve involvement in the current study may reflect the relatively large proportion of skull base and infratentorial tumors (43.3%), where cranial nerves are more susceptible to compression or infiltration.

Regarding tumor location, supratentorial meningiomas were predominant (56.7%), followed by skull base (30%) and infratentorial lesions (13.3%). This distribution is comparable to that reported by Ressel et al. (2019), who noted convexity (30%), falcine (12.5%), parasagittal (8.8%) and posterior fossa (14.6%) as the most frequent sites (2). Likewise, Haji mohammad Ebrahim- Ketabforoush et al. found 75% supratentorial and 10.7% infratentorial tumors in a large MRI-based cohort [15]. The relative predominance of supratentorial lesions underscores the importance of cortical venous drainage and regional anatomy in influencing PTBE formation.

Histopathological analysis revealed that Grade I meningiomas comprised the majority (76.7%), predominantly meningothelial (50%), followed by fibrous (10%) and transitional (6.7%) subtypes. Grade II tumors accounted for 23.3% of cases, mainly atypical and chordoid variants (10% each), while no Grade III tumors were detected. This distribution mirrors the low global incidence of anaplastic meningiomas (<1%) reported by Ressel et al. [1].

The distribution of the Edema Index followed a clear gradation pattern. Among Grade I tumors, 78.3% exhibited EI >1.0 and 21.7% had no or minimal edema (EI = 1.0). In contrast, all Grade

II tumors displayed EI >1.0 and 71.4% showed EI >2.0. These findings are consistent with Hale et al., who reported EI >2 in 64% of Grade II tumors compared to 32% in Grade I [13]. The trend indicates that PTBE severity tends to escalate with tumor grade, reflecting a possible relationship between aggressive histological features—such as high mitotic index and brain invasion—and the disruption of the blood–brain barrier.

The underlying mechanisms linking higher edema index to tumor grade remain multifactorial. Lee et al. suggested that increased vascular endothelial growth factor (VEGF) expression in higher-grade meningiomas enhances vascular permeability and peritumoral fluid accumulation [8]. Lin et al. and Hsu et al. also observed that atypical and malignant meningiomas demonstrate greater microvascular density and VEGF positivity, correlating with higher EI values [4,16]. Although some studies have reported inconsistent associations due to variations in imaging techniques and tumor heterogeneity, the present results reveal a consistent, statistically significant correlation, reinforcing EI's diagnostic value.

The present findings highlight the clinical utility of EI as a non-invasive preoperative indicator for tumor grading. By estimating the extent of peritumoral edema, surgeons and radiologists can better anticipate surgical complexity, intraoperative brain swelling and potential postoperative complications. Moreover, integrating EI into routine MRI interpretation could improve risk stratification, aiding decisions on the extent of resection, use of adjuvant therapy and follow-up strategies.

In summary, the consistent association observed between EI and tumor grade across all Grade II meningiomas in this study emphasizes its potential prognostic significance. As higher EI values have been linked with increased recurrence and poorer outcomes, EI could serve not only as a diagnostic adjunct but also as a predictor of disease progression. Incorporating such radiological markers into clinical algorithms may refine patient counseling, guide perioperative planning and promote precision in meningioma management. Future research involving larger multicentric cohorts and molecular correlations (e.g., VEGF, MMP-9 and progesterone receptor expression) could validate and expand upon these findings.

5. Limitations of the Study

The study was conducted at a single institution with a relatively small sample size, which may limit the generalizability of the findings to a larger, more diverse population. Histopathological exams were performed by various consultants and of the 30 patients, no grade III (anaplastic) meningioma was found.

6. Conclusion

This study highlights a significant relationship between the edema index and histopathological grading of meningiomas, with higher edema values consistently associated with more aggressive tumor grades. The findings support that the higher edema index (> 2.0) has a higher probability of being a high-grade meningioma. This may be used as a valuable tool for preoperative grading, informing surgical planning and potentially guiding treatment decisions.

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Conflicts Of Interest

There are no conflicts of interest.

Ethical Approval

The study was approved by the Institutional Ethics Committee.

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