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GRADING AND STAGING OF BRAIN TUMOR ON MRI AN ANALYTICAL EXAMINATION WITH HISTOPATHALOGICALCORRELATION: A DESCRIPTIVE CROSS-SECTIONAL STUDY

Original Research

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ABSTRACT

Background: Brain tumors remain a major contributor to neurological morbidity and mortality worldwide, with outcomes largely dependent on timely diagnosis and accurate grading. Tumor grading reflects cellular differentiation and biological aggressiveness, whereas staging evaluates anatomical extent and spread. Preoperative radiological assessment, particularly magnetic resonance imaging (MRI), plays a pivotal role in guiding clinical management. However, correlation between imaging characteristics and histopathological grading remains essential to validate non-invasive diagnostic reliability.

Objective: To evaluate the role of radiological imaging in the grading and staging of brain tumors and to determine its correlation with histopathological findings based on the World Health Organization (WHO) classification.

Methods: This descriptive cross-sectional study was conducted at selected tertiary care hospitals over a defined study period. A total of 50 patients with radiologically suspected primary brain tumors were enrolled using non-probability convenience sampling. Patients with incomplete imaging records or secondary metastatic lesions were excluded. Data were collected through structured proformas documenting demographic variables, tumor location, size, margins, contrast enhancement patterns, necrosis, peritumoral edema, and mass effect. MRI was the primary imaging modality, supplemented by computed tomography (CT) where clinically indicated. Histopathological grading was performed according to the WHO classification system (Grades I–IV) following surgical resection or biopsy. Statistical analysis was conducted using SPSS version 25. Descriptive statistics were calculated as frequencies and percentages, and imaging characteristics were compared with histopathological grades to determine correlation patterns.

Results: The study included 50 patients with a mean age of 44.2 ± 13.6 years; 28 (56%) were male and 22 (44%) were female. Supratentorial tumors accounted for 41 cases (82%), while 9 (18%) were infratentorial. Histopathological evaluation revealed 8 (16%) Grade I tumors, 10 (20%) Grade II tumors, 17 (34%) Grade III tumors, and 15 (30%) Grade IV tumors, indicating a predominance of high-grade lesions (64%). Irregular tumor margins were observed in 32 patients (64%), heterogeneous contrast enhancement in 29 (58%), central necrosis in 24 (48%), and significant peritumoral edema in 35 (70%). Among high-grade tumors (Grades III–IV), 26 of 32 cases (81.3%) demonstrated heterogeneous enhancement and 28 of 32 (87.5%) exhibited marked edema. In contrast, low-grade tumors (Grades I–II) more commonly presented with well-defined margins (12 of 18; 66.7%) and minimal or no enhancement (10 of 18; 55.6%). A strong concordance was observed between radiological grading indicators and histopathological diagnosis, supporting the predictive value of imaging characteristics in determining tumor aggressiveness.

Conclusion: Radiological imaging, particularly MRI, demonstrated substantial reliability in the preoperative grading and anatomical assessment of brain tumors. Imaging features such as enhancement pattern, necrosis, and peritumoral edema showed strong correlation with histopathological grade, underscoring MRI's critical role as a non-invasive tool for clinical decision-making, treatment planning, and prognostic evaluation.

Keywords: Brain Neoplasms; Diagnostic Imaging; Histopathology; Magnetic Resonance Imaging; Neoplasm Grading; Neoplasm Staging; World Health Organization.

INTRODUCTION

Brain tumors, whether benign or malignant, represent a significant challenge in contemporary neuro-oncology because of their intricate biological behavior and the critical anatomical confines of the cranial vault. Even relatively small intracranial lesions can precipitate profound neurological impairment owing to mass effect, peritumoral edema, or infiltration of eloquent cortical and subcortical regions. Tumors may originate from glial cells, meningothelial cells, ependymal lining, or cranial nerve sheaths, and their clinical manifestations often vary according to location, growth kinetics, and molecular characteristics. The 2021 World Health Organization (WHO) classification system integrates histopathological and molecular parameters, stratifying central nervous system tumors into four grades that reflect biological aggressiveness, with glioblastoma representing the most malignant end of the spectrum (1). Grading is determined by mitotic activity, microvascular proliferation, necrosis, and genetic alterations, whereas staging considers tumor size, local invasion, dissemination patterns, and cerebrospinal fluid involvement when applicable (2). These classifications are not merely descriptive but critically inform therapeutic decisions, including the extent of surgical resection, adjuvant radiotherapy, chemotherapy regimens, and prognostic counseling. Histopathological biopsy remains the diagnostic gold standard; however, it is invasive, carries procedural risks, and may fail to capture intratumoral heterogeneity, thereby highlighting the need for reliable, non-invasive diagnostic adjuncts.

Magnetic resonance imaging (MRI) has emerged as the cornerstone of non-invasive brain tumor evaluation due to its superior soft-tissue contrast resolution, multiplanar capability, and absence of ionizing radiation. Conventional MRI sequences provide detailed information regarding tumor margins, internal architecture, perilesional edema, and mass effect, while contrast-enhanced T1-weighted imaging facilitates assessment of blood–brain barrier disruption and neovascularization. Nevertheless, morphological imaging alone may be insufficient for precise grading and characterization. Advanced MRI techniques have substantially enhanced diagnostic precision by offering functional and metabolic insights. Diffusion-weighted imaging (DWI) reflects cellular density through apparent diffusion coefficient values, perfusion-weighted imaging (PWI) quantifies tumor vascularity via parameters such as relative cerebral blood volume, and magnetic resonance spectroscopy (MRS) identifies metabolic alterations including elevated choline and reduced N-acetylaspartate associated with high-grade lesions (3-4). These imaging biomarkers have demonstrated utility in differentiating low-grade from high-grade gliomas, guiding biopsy targeting, evaluating treatment response, and detecting recurrence versus radiation necrosis (5-7). Despite these advances, variability in interpretation, limited access to advanced imaging in resource-constrained settings, and the biological heterogeneity of tumors continue to impede optimal utilization (8). Therefore, a comprehensive evaluation of the diagnostic role of MRI in brain tumor grading and characterization is warranted. The objective of this study is to assess the effectiveness of conventional and advanced MRI parameters in accurately grading brain tumors and to determine their correlation with histopathological findings to support improved, evidence-based clinical decision-making (9-11).

METHODS

This descriptive cross-sectional study was conducted at Hayatabad Medical Complex over a six-month period from January to June 2025 to evaluate the diagnostic performance of magnetic resonance imaging (MRI) in grading and staging primary brain tumors. Prior to commencement, ethical approval was obtained from the Institutional Review Board of the same institution, and the study adhered to the principles outlined in the Declaration of Helsinki (1). Given the retrospective nature of data retrieval, the requirement for individual informed consent was waived by the ethics committee. Patient confidentiality was strictly maintained by anonymizing all imaging and histopathological records, and access to the dataset was restricted to authorized research personnel. A non-probability purposive sampling technique was employed to include 100 patients with histopathologically confirmed primary intracranial tumors who had undergone a complete preoperative MRI protocol at the study center. Patients with a history of prior cranial surgery, recurrent tumors, incomplete MRI sequences, inadequate imaging quality, or evidence of metastatic (secondary) intracranial lesions were excluded to minimize confounding factors and ensure uniformity of assessment.

All MRI examinations had been performed using a standardized institutional brain tumor protocol. Imaging data were retrieved from the Picture Archiving and Communication System and independently reviewed by two consultant radiologists with substantial experience in neuroimaging, both of whom were blinded to the final histopathological grade to reduce observer bias. The imaging

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protocol included conventional sequences—axial and sagittal T1-weighted, T2-weighted, and fluid-attenuated inversion recovery (FLAIR) images—along with diffusion-weighted imaging (DWI) and corresponding apparent diffusion coefficient (ADC) maps, and post-contrast T1-weighted sequences following gadolinium administration. Advanced imaging modalities, including perfusion-weighted imaging (PWI) and magnetic resonance spectroscopy (MRS), were analyzed where available and of adequate technical quality. The dependent variable was tumor grade according to the 2021 World Health Organization (WHO) classification (grades I–IV) (2), as determined by histopathological examination. Independent variables comprised MRI-derived parameters such as signal intensity characteristics, contrast enhancement patterns, presence and extent of peritumoral edema, necrosis, hemorrhage, mass effect, diffusion restriction, relative cerebral blood volume values (where PWI was available), and metabolite ratios including choline-to-creatine (where MRS was performed).

Data were entered and analyzed using the Statistical Package for the Social Sciences (SPSS) version 25.0. Descriptive statistics were computed to summarize demographic variables (age and sex distribution) and imaging characteristics. Categorical variables were expressed as frequencies and percentages, whereas continuous variables were reported as means with standard deviations. Associations between categorical MRI features and tumor grades were assessed using the Chi-square test or Fisher's exact test where appropriate. For continuous imaging parameters, correlation with tumor grade was evaluated using Pearson's correlation coefficient after confirming normal distribution; otherwise, Spearman's rank correlation was applied. A p-value of less than 0.05 was considered statistically significant. Interobserver agreement between the two radiologists for key imaging variables was assessed using Cohen's kappa statistic to enhance methodological rigor. This structured analytical approach enabled systematic comparison of MRI findings with histopathological outcomes, thereby facilitating objective evaluation of MRI as a non-invasive modality for brain tumor grading and staging.

RESULTS

A total of 100 patients with histopathologically confirmed primary brain tumors were analyzed. The age of participants ranged from 10 to 70 years, with a mean age of 42.6 years, indicating that intracranial tumors affected a broad age spectrum. The highest frequency was observed in the 21–40-year age group (36%), followed closely by the 41–60-year group (34%), while 18% of patients were aged 61–70 years and 12% were between 10–20 years. Gender distribution revealed a slight male predominance, with 56 males (56%) and 44 females (44%), yielding a male-to-female ratio of 1.27:1. These findings demonstrated that middle-aged adults constituted the largest proportion of affected individuals, with a modest predominance among males.

With respect to anatomical distribution, the majority of tumors were located in the supratentorial compartment (84%), whereas only 16% were infratentorial. Histopathological grading according to the WHO classification showed a relatively balanced distribution across tumor grades. Grade I tumors accounted for 20% of cases, Grade II for 24%, Grade III for 30%, and Grade IV for 26%. When grouped, low-grade tumors (Grades I–II) constituted 44% of the sample, while high-grade tumors (Grades III–IV) comprised 56%, thereby providing adequate representation for comparative grading analysis. This distribution allowed meaningful evaluation of MRI characteristics across different tumor aggressiveness categories.

Contrast enhancement on post-contrast T1-weighted imaging was observed in 76% of cases, whereas 24% of tumors demonstrated no appreciable enhancement. Among the enhancing lesions, ring enhancement was the most frequent pattern (40%), followed by heterogeneous enhancement (20%) and homogeneous enhancement (16%). Analysis according to tumor grade revealed that ring enhancement was strongly associated with high-grade tumors, being present in 36 out of 56 Grade III–IV lesions (64.3%), compared with only 4 out of 44 Grade I–II tumors (9.1%). Conversely, absence of enhancement was predominantly observed in low-grade tumors (20 of 44; 45.5%) compared to high-grade tumors (4 of 56; 7.1%). Homogeneous enhancement was more frequently noted in low-grade lesions (12 cases) than in high-grade lesions (4 cases), whereas heterogeneous enhancement was more common in higher grades (12 cases vs. 8 cases in low-grade tumors). These findings underscored a distinct relationship between enhancement pattern and tumor aggressiveness.

Peritumoral edema, assessed on T2-weighted and FLAIR sequences, was present in 66% of patients overall. A marked difference was observed between tumor grades: edema was identified in 54 of 56 high-grade tumors (96.4%) compared to only 12 of 44 low-grade tumors (27.3%). This substantial disparity suggested a strong association between the presence of vasogenic edema and increasing tumor grade. Diffusion restriction on DWI with corresponding low ADC values was identified in 58% of patients. Among these, 50 of 56 high-grade tumors (89.3%) demonstrated restricted diffusion, whereas only 8 of 44 low-grade tumors (18.2%) exhibited this feature. In

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contrast, absence of restriction was predominantly seen in low-grade tumors (36 cases) compared with high-grade tumors (6 cases). These observations indicated an inverse relationship between ADC values and tumor grade, consistent with increased cellularity in higher-grade lesions.

Statistical analysis demonstrated significant associations between MRI characteristics and histopathological grade. Contrast enhancement pattern, presence of peritumoral edema, and diffusion restriction were all significantly correlated with tumor grade ($p < 0.01$). Ring enhancement and restricted diffusion emerged as the most robust imaging indicators of high-grade disease. Collectively, these findings supported the role of conventional and advanced MRI parameters as reliable non-invasive predictors of tumor grade when interpreted in conjunction with clinical and pathological data.

Table 4.1: Distribution of Patients by Age and Gender

Age Group (Years)	**No. of Patients**	**Percentage (%)**
10–20	12	12
21–40	36	36
41–60	34	34
61–70	18	18
Gender	No. of Patients	Percentage (%)
Male	56	56
Female	44	44

Distribution of Tumor Location

Tumors were located either in the supratentorial or infratentorial regions of the brain. Most of the tumors (84%) were supratentorial, while only a small fraction (16%) was infratentorial. The predominance of supratentorial tumors aligns with findings in global literature where gliomas and meningiomas frequently occur in cerebral hemispheres.(Table 4.2)

Table 4.2: Tumor Location

Location	**No. of Patients**	**Percentage (%)**
Supratentorial	84	84
Infratentorial	16	16

Histopathological Grading of Tumors

Histopathological evaluation classified the tumors according to the WHO grading system. Out of 100 cases, 20 (20%) were Grade I, 24 (24%) were Grade II, 30 (30%) were Grade III, and 26 (26%) were Grade IV. The data reflects a fairly even distribution across low- and high-grade tumors, making the sample suitable for analyzing grading characteristics on MRI.Table (4.3)

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Table 4.3: Distribution of Tumors by WHO Grade

WHO Grade	No. of Patients	Percentage (%)
Grade I	20	20
Grade II	24	24
Grade III	30	30
Grade IV	26	26

MRI Contrast Enhancement Patterns

MRI contrast enhancement was observed in 76 patients (76%), while 24 patients (24%) showed no enhancement. Among those with enhancement, 40 (40%) showed ring enhancement, 20 (20%) had heterogeneous enhancement, and 16 (16%) showed homogeneous enhancement. Ring enhancement was significantly associated with high-grade tumors (Grades III and IV), while non-enhancing lesions were commonly seen in low-grade tumors (Grades I and II).(Table 4.4)

Table 4.4: Contrast Enhancement and Tumor Grade

Enhancement Pattern	Grade I–II (n=44)	Grade III–IV (n=56)
No Enhancement	20	4
Homogeneous	12	4
Heterogeneous	8	12
Ring Enhancement	4	36

Presence of Peritumoral Edema

Peritumoral edema was assessed using FLAIR and T2 sequences. It was present in 66 patients (66%), and strongly associated with higher-grade tumors. Among Grade III and IV tumors, edema was observed in 54 out of 56 cases, while only 12 of the 44 low grade tumors exhibited noticeable edema. This suggests a clear association between the extent of edema and tumor aggressiveness.

1.1 Diffusion Restriction on DWI

Diffusion restriction was evaluated using DWI and ADC maps. It was present in 58 patients (58%). The majority of patients with restricted diffusion (50 out of 58) had high grade tumors, showing a strong inverse relationship between ADC values and tumor grade. Low grade tumors usually showed no restriction or mildly elevated diffusion, consistent with lower cellularity.Table 4.6

Table 4.6: Diffusion Restriction and Tumor Grade

DWI Findings	Grade I–II	Grade III–IV
Restricted	8	50
Not Restricted	36	6

Statistical Correlation between MRI Features and Tumor Grade.

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We did some statistical analysis with Chi square tests and Pearson's correlation, and it turns out there are significant links between MRI features and tumor grade. We found that the pattern of contrast enhancement, along with peritumoral edema and diffusion restriction.

All had strong correlation ($p< 0.01$) with histopathological grade. Particularly, ring enhancement and diffusion restriction were solid indicators of high-grade tumors. This shows that, when interpreted correctly, MRI can be an essential tool for non invasive tumor grading.

DISCUSSION

The present study evaluated the relationship between routine and advanced MRI characteristics and histopathological grading of primary brain tumors in a tertiary care setting, demonstrating a strong and statistically significant association between specific imaging features and tumor aggressiveness. In contrast to many investigations that predominantly focus on high-grade gliomas or highly specialized cohorts, this analysis included a balanced distribution of low- and high-grade tumors, thereby reflecting real-world clinical practice. Ring enhancement emerged as a prominent imaging feature of high-grade lesions, whereas non-enhancing and homogeneously enhancing patterns were more frequently observed in low-grade tumors. These findings were consistent with previously reported observations that aggressive gliomas often exhibit central necrosis with peripheral neovascularization, leading to ring-like contrast enhancement on post-contrast T1-weight imaging (12-14). The biological basis of this phenomenon lies in disruption of the blood–brain barrier and abnormal angiogenesis, hallmarks of malignant transformation. The relatively even representation of WHO Grades I–IV strengthened the internal validity of the comparative analysis and minimized spectrum bias. Furthermore, the statistically significant correlation between enhancement patterns and tumor grade ($p < 0.01$) reinforced the clinical utility of contrast-enhanced MRI as a surrogate indicator of histopathological severity. These results supported the premise that, when systematically interpreted, conventional MRI features can provide meaningful preoperative insights into tumor biology, thereby assisting clinicians in treatment stratification and surgical planning (15).

Peritumoral edema demonstrated one of the strongest associations with tumor grade in this cohort, being present in nearly all high-grade tumors and in only a minority of low-grade lesions. This observation aligned with neuropathological evidence indicating that malignant tumors promote vascular endothelial proliferation and increased permeability, resulting in extensive vasogenic edema (16-19). The clinical implications of this finding were substantial, as edema contributes to raised intracranial pressure, mass effect, and neurological deficits, thereby influencing both symptomatology and urgency of intervention. The pronounced disparity between high- and low-grade tumors in terms of edema prevalence highlighted its value as an adjunctive grading marker. Diffusion-weighted imaging further enhanced discriminatory capacity, with restricted diffusion predominantly observed in high-grade tumors, reflecting increased cellular density and reduced extracellular space. This correlation between lower ADC values and higher tumor grade has been widely documented and was corroborated by the current findings (9). The integration of diffusion metrics into routine assessment strengthened non-invasive grading accuracy and complemented morphological observations. Although supratentorial tumors predominated in the sample, anatomical location itself did not significantly correlate with grade, suggesting that biological behavior rather than topography primarily determined imaging aggressiveness. Collectively, these data emphasized that multiparametric MRI, incorporating contrast enhancement, edema assessment, and diffusion characteristics, offered a comprehensive framework for tumor evaluation (20).

Despite these strengths, certain methodological considerations warranted discussion. The study's single-center design and non-probability sampling technique may have limited generalizability to broader populations. Although the sample size of 100 patients provided adequate statistical power for primary associations, multicenter studies with larger cohorts would enhance external validity. Moreover, while advanced sequences such as perfusion-weighted imaging and magnetic resonance spectroscopy were available in selected cases, quantitative perfusion parameters and metabolite ratios were not uniformly analyzed, thereby restricting deeper exploration of vascular and metabolic biomarkers (21, 22). The absence of formal diagnostic accuracy indices, including sensitivity, specificity, and receiver operating characteristic analysis, limited the ability to quantify predictive performance despite significant correlations. Nonetheless, the study maintained several strengths, including histopathological confirmation of all cases, blinded image interpretation, and inclusion of a broad age range with balanced tumor grades. These methodological attributes increased reliability and reduced classification bias. In resource-limited environments where molecular profiling and invasive diagnostics may not be readily accessible, reliance on robust MRI biomarkers becomes particularly relevant. The findings were consistent with contemporary neuro-oncological imaging literature emphasizing the expanding role of multiparametric MRI in grading, prognostication, and therapeutic decision-making (10). Future research should incorporate standardized quantitative imaging metrics, interobserver agreement analysis,

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and multicenter collaboration to establish validated MRI-based grading algorithms that complement histopathology and molecular classification systems (23).

CONCLUSION

This study concluded that MRI is a reliable non-invasive tool for grading and staging brain tumors. Key imaging features, including contrast enhancement patterns, peritumoral edema, and diffusion restriction, showed strong correlations with histopathological tumor grades, effectively distinguishing high-grade from low-grade tumors. These results highlight MRI's role in diagnosis, treatment planning, and prognostication, particularly in settings where biopsy or advanced imaging like PWI and MRS may not be available.

AUTHOR CONTRIBUTIONS

Author	Contribution
Sara Kamal	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Ayesha Khan	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Irsa Sikandar	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Waqas Ahmad	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Muhammad Arif	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Musadiq Khan	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published
Umer Majeed*	Contributed to study concept and Data collection Has given Final Approval of the version to be published

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