RESEARCH PAPER

Diagnostic Accuracy of Conventional and Advanced MRI For Histopathological Grading of Glioma

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Received: 17th Mar, 2026 | Revised: 29th Mar, 2026 | Accepted: 19th Apr, 2026 | Available Online: 5th May, 2026

ABSTRACT
Glioma is the most common primary tumor of the central nervous system, with a wide spectrum of malignancy grades based on the 2021 WHO classification integrating histopathological and molecular features. Accurate tumor grading is essential for treatment planning and prognosis. Although histopathology remains the gold standard, it is invasive and subject to sampling bias and inter-observer variability. Multiparametric MRI has emerged as a promising non-invasive alternative. However, most existing studies are derived from large international centers, with limited data from local populations, particularly in Indonesia. In addition, few studies have comprehensively evaluated the combined role of conventional and advanced MRI techniques in direct comparison with histopathological grading within a single institutional setting using the WHO 2021 framework. This study aimed to evaluate the diagnostic performance of conventional and advanced MRI techniques in determining glioma malignancy grade and to assess their agreement with histopathological findings based on the WHO 2021 classification in a local clinical setting. This descriptive analytic cross-sectional study utilized secondary data from glioma patients treated at Dr. Soetomo General Hospital between April 2021 and January 2025. Eligible subjects were adults (≥18 years) with complete multiparametric MRI data including conventional MRI, diffusion-weighted imaging (DWI/ADC), dynamic susceptibility contrast (DSC) perfusion, and magnetic resonance spectroscopy (MRS) as well as histopathological and molecular confirmation based on the 2021 WHO classification. Parameters assessed included contrast enhancement patterns on T1-weighted imaging, ADC values, relative cerebral blood volume (rCBV), and metabolite ratios (Cho/Cr and Cho/NAA). Statistical analyses were conducted to evaluate correlations, sensitivity, and specificity relative to histopathological grading. High-grade gliomas typically showed intense, heterogeneous contrast enhancement accompanied by necrosis. These tumors had significantly lower ADC values compared to low-grade gliomas. In addition, rCBV values were markedly higher in high-grade tumors, indicating increased angiogenesis. Metabolite ratios (Cho/Cr and Cho/NAA) were also elevated in high-grade gliomas. Overall, advanced MRI modalities demonstrated greater sensitivity and specificity than conventional MRI in distinguishing tumor grades. Multiparametric MRI shows a significant correlation with histopathological grading and enhances the accuracy of non-invasive preoperative assessment of glioma malignancy.

Keywords: Glioma, Multiparametric Mri; Dwi/Adc; Dsc Perfusion; Magnetic Resonance Spectroscopy, Rcbv; Histopathological Grading; Who 2021 Classification.
How to cite this article: Hidayat P R, Sensusiati A D, Ferriastuti W., Diagnostic Accuracy of Conventional and Advanced MRI For Histopathological Grading of Glioma. Int J Drug Deliv Technol. 2026;16(43s): 728-741; Doi: 10.25258/Ijddt.16.43s.74
Source of support: Nil.
Conflict of interest: None

INTRODUCTION

A primary brain tumor that originates from glial cells, glioma is also the central nervous system's most frequently occurring malignancy. Subtypes vary according to the source cell and include astrocytoma, oligodendroglioma, and glioblastoma. Roughly 30% of all primary brain tumors are gliomas, and these tumors also constitute up to 80% of malignant brain tumor cases. Determining the malignancy grade of glioma is crucial, as it is closely related to treatment planning and prognosis prediction. Even though histopathological examination continues to serve as the benchmark for

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diagnosing and grading tumors, this approach suffers from certain drawbacks. Sampling mistakes and differences in judgment across pathologists are notable issues. As a result, a non-invasive technique is required to assess tumor malignancy more thoroughly before any surgical procedure or biopsy takes place.[1]

From an epidemiological perspective, IDH-mutant gliomas are more frequently found in younger adults, whereas IDH-wildtype glioblastomas tend to occur in older individuals. The occurrence of gliomas is influenced by both genetic and environmental factors, although definitive risk factors are not yet fully understood. Studies have shown that exposure to ionizing radiation is the most consistent risk factor, while other factors such as family history, genetic mutations, and exposure to certain chemicals still require further evidence.[1,2]

Several multi-center studies conducted in China have demonstrated that combining MRI morphological features, diffusion parameters (such as ADC), and metabolite profiles from functional imaging can accurately predict glioma tumor grade as well as molecular status, including IDH mutant/wildtype and 1p/19q codeletion, prior to invasive procedures. These studies reported an area under the ROC curve (AUROC) above 0.8–0.93, sensitivity exceeding 80–90%, and specificity above 75%.[3] These findings support the integration of imaging diagnostics not only for predicting tumor grade but also for advancing personalized medicine, allowing treatment strategies to be tailored based on non-invasive predictions before invasive procedures are performed.

However, despite these advancements, several important gaps remain. Most existing studies are conducted in large international centers, and there is limited evidence from local populations, particularly in Indonesia. Furthermore, only a small number of studies have thoroughly investigated how conventional MRI together with advanced MRI methods like diffusion, perfusion, and spectroscopy performs when directly compared against histopathological grading, all within the same institution.[1,2] Additionally, variability in imaging protocols and the lack of standardized integration with WHO 2021 classification criteria limit the generalizability of prior findings. No prior investigation has specifically looked into the diagnostic accuracy of combining standard and sophisticated MRI techniques for grading gliomas at Surabaya's Dr. Soetomo General Hospital.

Therefore, this study addresses these gaps by providing a comprehensive evaluation of multiparametric MRI in a local clinical setting, integrating conventional MRI, diffusion imaging (DWI/ADC), perfusion (DSC), and MR spectroscopy, and directly comparing these findings with histopathological grading based on WHO 2021 classification. This approach represents an advancement over previous studies by offering region-specific data, applying a multimodal imaging framework, and emphasizing clinical applicability in routine practice.

Magnetic Resonance Imaging (MRI) remains the primary imaging modality for evaluating glioma. Conventional MRI sequences (T1, T2, FLAIR) assess tumor morphology, lesion boundaries, edema, and mass effect. Typically, gliomas appear hypointense on T1-weighted images and hyperintense on T2/FLAIR, with contrast enhancement more commonly observed in high-grade tumors. Advanced MRI techniques further enhance tumor characterization: diffusion imaging (DWI/ADC) reflects cellularity, where lower ADC values indicate higher tumor grade; perfusion MRI assesses tumor vascularity via parameters such as relative cerebral blood volume (rCBV), which is elevated in high-grade tumors; and MR spectroscopy evaluates metabolic alterations, including increased choline and decreased N-acetylaspartate (NAA), associated with malignancy. The integration of these modalities with histopathological confirmation is expected to improve diagnostic accuracy and support multidisciplinary decision-making.[1]

Evaluating the diagnostic accuracy of both conventional and advanced MRI for glioma grading represents the primary aim of this research. A further objective involves comparing these MRI findings against histopathological data in accordance with the WHO 2021 classification. This study is expected to provide both academic and clinical contributions. Academically, it enriches the current literature on multiparametric MRI in glioma evaluation, particularly within the framework of WHO 2021 classification. Clinically, it supports the use of non-invasive imaging to improve the accuracy and efficiency of glioma grading, ultimately contributing to better treatment planning and patient outcomes.

METHODS

Research Design

This research applied a cross sectional, descriptive analytic design to examine glioma brain tumors. The patients had received MRI evaluation through four techniques: structural imaging, diffusion weighted imaging (DWI/ADC), dynamic susceptibility contrast (DSC) perfusion, and magnetic resonance spectroscopy (MRS). Histopathological and molecular findings were used as the reference standard for

determining tumor malignancy grade. Data were obtained through retrospective review of medical records of patients who had undergone multimodal MRI examinations and histopathological-molecular confirmation within a defined period at Dr. Soetomo General Hospital. Collected data included patient demographics, MRI findings (conventional MRI, DWI/ADC, perfusion, and spectroscopy), and histopathological and molecular results based on the WHO 2021 classification. All data were retrieved from fully documented hospital medical records at Dr. Soetomo General Hospital, Surabaya.

Time and Setting

The study was conducted in August 2025 using secondary data. Data were obtained from patients who had undergone MRI examinations at the Radiodiagnostic Installation of Dr. Soetomo General Hospital and met the inclusion and exclusion criteria.

Study Population and Sample

All MRI data from patients with confirmed glioma brain tumors formed the study population. These patients had undergone imaging between April 2021 and January 2025 at the MRI unit located within the Radiodiagnostic Installation of Dr. Soetomo General Hospital in Surabaya.

The study sample included subjects who met the predefined inclusion and exclusion criteria. A total sampling (non-probability sampling) technique was used. Based on sample size calculation for sensitivity and specificity using an AUC of 0.9, $\alpha = 0.05$, and estimation error (d) = 0.1, a total of 44 samples were required, consisting of 13 low-grade and 31 high-grade gliomas. Inclusion criteria were patients aged ≥18 years, those with a confirmed diagnosis of glioma based on histopathological and molecular examination, patients with complete multiparametric MRI examinations (conventional MRI, DWI/ADC, perfusion, and spectroscopy), and availability of complete electronic medical record data within the study period (April 2021–January 2025). Exclusion criteria included patients diagnosed with other intracranial tumors such as meningioma, patients with brain metastases, and patients with brain abscess.

Study Variables

The independent variables consisted of multimodal MRI findings, including conventional MRI characteristics (lesion size, margins, edema, mass effect, and contrast enhancement on T1, T2, and FLAIR sequences), Several parameters were measured. ADC values derived from DWI/ADC served as indicators of tumor cellularity. Relative cerebral blood volume (rCBV) obtained from perfusion imaging reflected the degree of tumor vascularity. Additionally, MR spectroscopy provided metabolite ratios such as Cho/Cr and Cho/NAA along with the presence of lactate peaks. The dependent variable was the tumor malignancy grade determined by histopathological and molecular examination (WHO grades 2, 3, or 4) based on the WHO 2021 classification.

Study Procedure

This cross-sectional study aimed to assess the correlation between glioma malignancy grading based on MRI findings (both conventional and advanced techniques) and histopathological grading according to WHO 2021 standards. Subjects meeting inclusion criteria were identified, and their MRI and histopathological data were collected, tabulated, and analyzed.

Data Collection and Processing

This study utilized secondary data from medical records and primary data from histopathological examinations, which served as the gold standard for tumor malignancy assessment. Data collected included results of conventional and advanced MRI examinations as well as histopathological findings. All gathered information was documented, organized into tables, and then processed with Statistical Package for the Social Sciences (SPSS) version 26.0 (IBM Corp., Chicago, IL, USA). Descriptive statistics were used to summarize the demographic features of the participants. MRI findings (conventional and advanced) were compared with histopathological results.

Statistical analyses included homogeneity testing using Levene's test, where a significance value >0.05 indicated homogeneous data. Normality was checked with the Shapiro–Wilk test, and distributions with p >0.05 were considered normal. Group comparisons relied on the independent t test provided the data were normal and homogeneous. The analysis proceeded with the Mann Whitney test under non normal conditions. Paired t tests were used to compare MRI findings with histopathological grading provided the data followed a normal distribution. If normality was not satisfied, the Wilcoxon test replaced the paired t test. To determine how well the MRI methods performed diagnostically against histopathological results, the study computed sensitivity, specificity, PPV, and NPV. A p value of less than 0.05 alongside a 95% confidence interval defined statistical significance.

Research Instruments

MRI examinations were performed using 1.5 Tesla GE Optima and 3 Tesla Siemens Skyra systems, including

structural imaging, DWI/ADC, DSC perfusion, and MR spectroscopy sequences.

Ethical Considerations

This investigation followed established ethical standards for medical research. Prior to gathering data, the research team secured ethical clearance from the Health Research Ethics Committee of Dr. Soetomo General Hospital. To preserve patient confidentiality, all data were anonymized, and only permitted researchers could view the original documents. The study did not involve additional interventions beyond standard clinical care, ensuring no additional risk to patients (non-maleficence). The research is expected to provide benefits by improving understanding of glioma malignancy and its correlation with MRI findings (beneficence).

RESULTS

Table 1. Baseline Characteristic for Study

Variable	Frequency (n=44)	Percentage (%)
Age		
Mean ± SD	43.89 ± 13.40 years	
Min–Max	21–76 years	
20–29 years	6	13.6%
30–39 years	16	36.4%
40–49 years	3	6.8%
50–59 years	14	31.8%
≥ 60 years	5	11.4%
Gender		
Male	24	54.5%
Female	20	45.5%
Location		
Frontal (frontal, frontotemporal, frontoparietal)	19	43.2%
Parietal (parietal, parietotemporal, parieto-occipital)	17	38.6%
Temporal (temporal, temporoparietal)	3	6.8%
Subcortical (thalamus, basal ganglia, ventricle, periventricular, insular)	5	11.4%
Primary Type of Glial Tumor		
Astrocytoma (astrocytoma, CNS WHO grade 2, xanthoastrocytoma)	22	50.0%
Oligodendroglioma (including anaplastic oligodendroglioma)	10	22.7%
Glioblastoma	10	22.7%
Others (infiltrating glioma)	2	4.5%
IDH Status		
NOS (Not Otherwise Specified)	34	77.3%
IDH Mutant (IDH-1 mutant, IDH mutant)	5	11.4%
IDH Wild Type	5	11.4%
CNS WHO Classification		
Grade 2	12	27.3%
Grade 3	14	31.8%
Grade 4	18	40.9%
T1 with Contrast (Conventional MRI)		
Hyperintense	16	36.4%
Heterointense	28	63.6%
DWI (Advanced MRI)		
Restricted	32	72.7%
Unrestricted	12	27.3%
Imaging Grade of Malignancy (Conventional MRI)		
Low	16	36.4%

High	28	63.6%
Imaging Grade of Malignancy (Advanced MRI)		
Low	16	36.4%
High	28	63.6%
Histopathology Grade		
Low	12	27.3%
High	32	72.7%
	Mean ±SD	Mean ±SD
rCBV (ml/100 g)	3.04 ± 1.19	1.0 – 7.1
MRS (Cho/Cr)	2.62 ± 1.21	1.0 – 6.0
MRS (Cho/NAA)	2.86 ± 1.63	1.0 – 8.1
ADC value (mean)	0.98 ± 0.29	0.60 – 1.9

Based on the demographic characteristics of the sample, the mean age of the participants was 43.89 ± 13.40 years, with an age range of 21–76 years**.** Most patients were in the 30–39 year age group (36.4%), followed by those aged 50–59 years (31.8%), while the 40–49 year group had the lowest proportion (6.8%). In terms of sex distribution, male patients (54.5%) outnumbered female patients (45.5%). Regarding tumor location, the majority were found in the frontal region (43.2%), followed by the parietal region (38.6%). Tumors located in the temporal region accounted for 6.8%, while subcortical locations (including the thalamus, basal ganglia, ventricles, periventricular region, and insular area) accounted for 11.4%.

Based on the main type of glial tumor, astrocytoma (including astrocytoma CNS WHO grade 2 and xanthoastrocytoma) was the most common (50.0%), followed by glioblastoma (22.7%) and oligodendroglioma (22.7%). Other types, such as infiltrating glioma, were relatively rare (4.5%). In terms of IDH mutation status, the majority of cases were classified as NOS (not otherwise specified) (77.3%), while IDH mutant and IDH wild-type tumors each accounted for 11.4%.

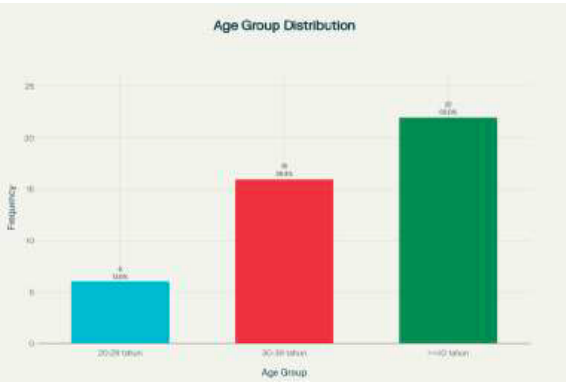

Figure 1. Age Group Distribution

Figure 2. Gender Group Distribution

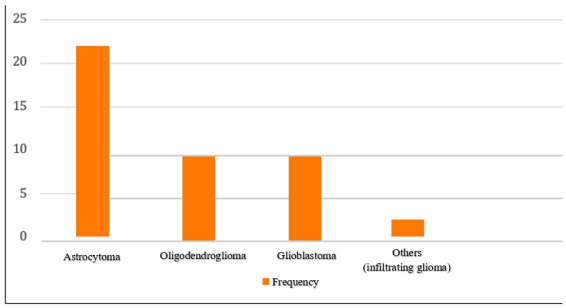

Figure 3. Primary Glial Tumor Distribution

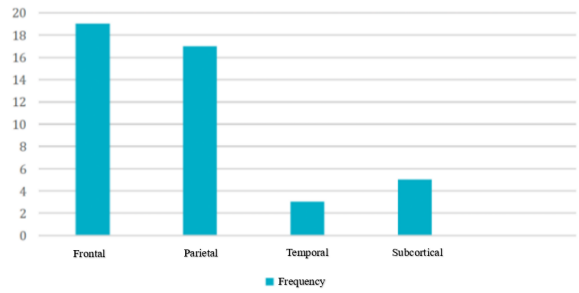

Figure 4. Tumor Site Distribution

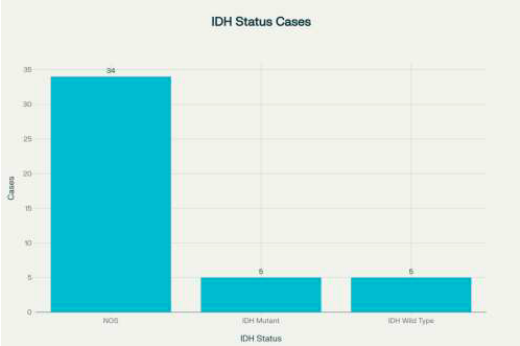

Figure 5. IDH Status Cases Distribution

Radiological and Histopathological Characteristics

Based on the CNS WHO classification, most patients were classified as grade 4 (40.9%), followed by grade 3 (31.8%) and grade 2 (27.3%). On conventional MRI, contrast-enhanced T1-weighted imaging showed heterogeneous enhancement in 63.6% of patients and hyperintense enhancement in 36.4%. On advanced MRI using diffusion-weighted imaging (DWI), most lesions demonstrated restricted diffusion (72.7%), while 27.3% showed no restriction. The assessment of tumor malignancy grade based on imaging revealed similar patterns between modalities. On conventional MRI, 63.6% of tumors were classified as high-grade, while 36.4% were low-grade. The same distribution was observed on advanced MRI. Histopathological examination also showed that most tumors were high-grade (72.7%), with low-grade tumors accounting for 27.3%. Overall, these findings indicate that the majority of patients in this study had high-grade gliomas, reflecting a predominance of aggressive tumor characteristics.

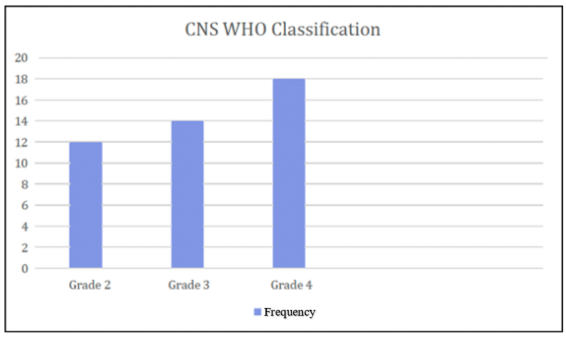

Figure 6. Tumor Classification based on WHO CNS Classification

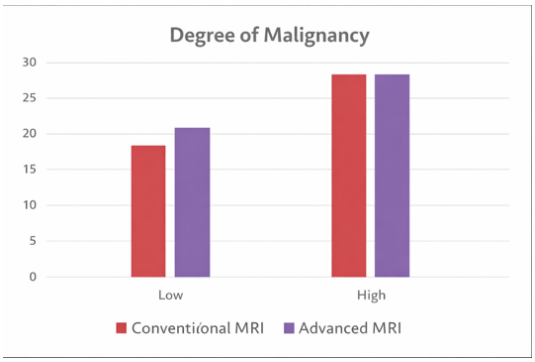

Figure 7. Comparison of Malignancy Degree between Conventional and Advanced MRI

Quantitative MRI Findings

Quantitative analysis from advanced MRI demonstrated a mean relative cerebral blood volume (rCBV) of 3.04 ± 1.19 ml/100 g (range 1.0–7.1). The mean MRS Cho/Cr ratio was 2.62 ± 1.21 (range 1.0–6.0), while the Cho/NAA ratio was 2.86 ± 1.63 (range 1.0–8.1). The mean ADC value was 0.98 ± 0.29 (range 0.60–1.9). These results suggest that most patients had high-grade tumors (grade 3–4) characterized by heterogeneous signal intensity on T1 and T2 imaging, presence of edema, diffusion restriction on DWI, and elevated rCBV and MRS ratios with relatively low ADC values, consistent with aggressive glioma profiles.

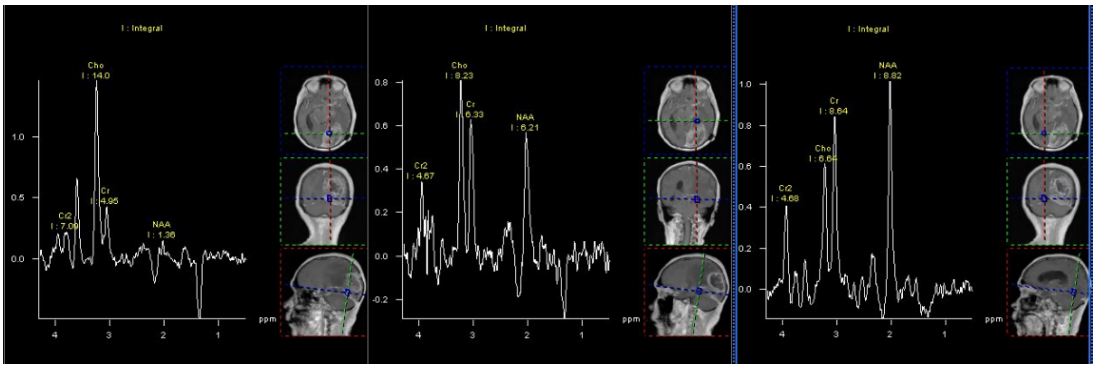

Figure 8. MRI Spectroscopy of High Grade Glioma

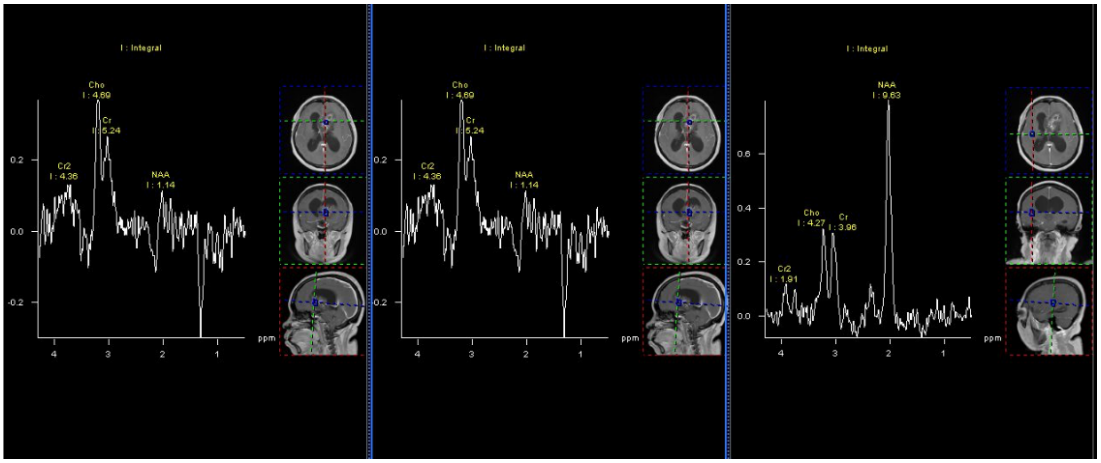

Figure 9. MRI Spectroscopy of Low Grade Glioma

Comparative Analysis of MRI Methods

Since the normality testing indicated a non normal data distribution, the Wilcoxon Signed Rank test was applied for the remaining analysis. The assessment of tumor malignancy grade using conventional MRI versus advanced MRI gave a p value of 1.000 ($p > 0.05$). This result confirms that the difference between the two imaging methods is not statistically significant. This suggests that conventional MRI provides results comparable to advanced MRI in evaluating tumor malignancy grade. Although advanced MRI offers additional quantitative parameters such as rCBV, MRS, and ADC, both methods demonstrate high consistency. Therefore, conventional MRI remains a reliable alternative, especially in settings where advanced MRI is not available.

Table 2. Conventional MRI Confusion Matrix and Performance

	Histopathology Grade (Low)	**Histopathology Grade (High)**	**Performance Metric**	**Value**
Imaging Grade: Conventional (Low)	9	7	Sensitivity	75.00%
Imaging Grade: Conventional (High)	3	25	Specificity	78.13%
Performance Metric	**Positive Predictive Value (PPV)**	**Negative Predictive Value (NPV)**	Accuracy	77.3%*
Value	56.25%	89.29%		

Table 3. Advanced MRI Confusion Matrix and Performance

	Histopathology Grade (Low)	**Histopathology Grade (High)**	**Performance Metric**	**Value**

Imaging Grade: Advanced (Low)	10	6	Sensitivity	83.3%
Imaging Grade: Advanced (High)	2	26	Specificity	80.6%
Performance Metric	**Positive Predictive Value (PPV)**	**Negative Predictive Value (NPV)**	Accuracy	81.4%*
Value	62.5%	92.6%		

Table 4. Summary of Sensitivity and Specificity Test Results for Advanced and Conventional MRI

Comparison	**Sensitivity**	**Specificity**	**Positive Predictive Value (PPV)**	**Negative Predictive Value (NPV)**	**Positive Likelihood Ratio (LR+)**	**Accuracy**
Conventional Imaging Malignancy Grade vs. HistoPA result	75.00 %	78.13 %	56.25%	89.29 %	3.43	77.3%
Advanced MRI Histopathology Grade vs. HistoPA result	83.3%	80.6%	62.5%	92.6%	4.31	81.4%

Sensitivity and Specificity Analysis of Conventional and Advanced MRI

Diagnostic testing results indicate that both conventional MRI and advanced MRI demonstrate good diagnostic performance when compared with histopathological findings as the gold standard. For conventional MRI, the sensitivity was 75.0% and specificity was 78.1%, indicating moderate ability to correctly identify both high-grade and low-grade tumors. The positive predictive value (PPV) was 56.3%, meaning that just over half of tumors classified as high-grade on MRI were confirmed histopathologically. The negative predictive value (NPV) was 89.3%, suggesting strong reliability in identifying low-grade tumors. The positive likelihood ratio was 3.43, and the overall accuracy was 77.3%, reflecting fairly good diagnostic capability. For advanced MRI, the sensitivity was higher at 83.3%, indicating improved detection of high-grade tumors. The specificity was 80.6%, also demonstrating good performance in identifying low-grade tumors. The PPV was 62.5%, while the NPV was 92.6%, showing excellent reliability for ruling out high-grade disease. The positive likelihood ratio was 4.31, and the overall accuracy reached 81.4%, indicating superior performance compared to conventional MRI.

DISCUSSION

Baseline Demographic Characteristics of the Study

The incidence and mortality of glioma differ based on age, sex, race, and geographic distribution. When classified according to ICD O 3 histology codes 9380 through 9384 and 9391 through 9460, gliomas account for about 24.5% of all primary brain tumors. Furthermore, these tumors constitute 80.9% of malignant brain tumors occurring in the adult population. In terms of anatomical distribution, the majority of gliomas (62%) arise in the supratentorial region, with the highest proportions located in the frontal lobe (27.0%), followed by the temporal (20.2%), parietal (11.6%), and occipital lobes (2.8%). The remaining cases are found in other regions of the central nervous system, including the brainstem (4.3%), spinal cord and cauda equina (4.0%), cerebellum (2.8%), and other intracranial locations (20.0%).[4,5] This study showed similar results, where 43.2% of samples had gliomas located in the frontal region (frontal/frontotemporal/frontoparietal).

The Central Brain Tumor Registry of the United States (CBTRUS) reports that astrocytic tumors, including glioblastoma, represent 77.5% of all gliomas. A breakdown of malignant gliomas shows glioblastoma as the predominant subtype (58.4%). The remaining proportions are as follows: diffuse astrocytoma (7.3%), anaplastic astrocytoma (6.8%), oligodendroglioma (3.5%), anaplastic oligodendroglioma (1.7%), pilocytic astrocytoma (5.0%), and other unspecified malignant gliomas or NOS (7.9%).[1,6] In this study, 22% of samples were Astrocytoma, IDH-mutant CNS WHO grade 2, representing the most common diagnosis during the sampling period.

Incidence rates among adults place glioblastoma highest at 3.23 per 100,000 population. Following this tumor are diffuse astrocytoma (0.46 per 100,000), anaplastic astrocytoma (0.42 per 100,000), oligodendroglioma (0.23 per 100,000), and anaplastic oligodendroglioma (0.11 per 100,000). When examining age, diffuse astrocytoma and oligodendroglioma typically arise in younger adults, with median ages of 46 and 43 years. In contrast, patients with anaplastic astrocytoma have a median age of 53 years, while those with anaplastic oligodendroglioma have a median age of 49 years. These anaplastic types therefore present approximately 5 to 9 years later than their lower grade equivalents.[7] Similar findings were observed in this study, where diagnoses were dominated by two age groups: 30–39 years (young adults) and 50–59 years (adults).

In adults and the elderly, glioblastoma represents the most common tumor, typically diagnosed at a median age of 65 years. Pediatric cases of glioblastoma are rare. For children, however, gliomas account for nearly 45% of all malignant central nervous system (CNS) tumors. Diffuse midline glioma accounts for the largest proportion of pediatric gliomas (31.1%),[7,8] followed by pilocytic astrocytoma (18.3%), diffuse and anaplastic astrocytoma (5.3%), and glioblastoma (2.6%). Among individuals aged 0–19 years, the incidence of diffuse midline glioma is estimated at 0.31 per 100,000 population,[7] followed by diffuse astrocytoma (0.23 per 100,000) and glioblastoma (0.17 per 100,000). High-grade tumors such as grade 3 astrocytoma, oligodendroglioma, and anaplastic oligodendroglioma are relatively rare, with incidence rates of 0.09, 0.04, and 0.01 per 100,000, respectively.[6,8] Males experience a higher overall incidence of glioma (5.51 per 100,000) than females (3.65 per 100,000). The only exception to this pattern is diffuse midline glioma, for which the incidence in females (0.324) slightly exceeds that in males (0.288).[8]

Glioma incidence may also be influenced by ethnicity. The incidence rate is approximately twice as high in populations from America and Northern Europe compared to Asian populations.[9] Additionally, in North America, Europe, and Oceania, glioblastoma constituted 80% of astrocytic tumors in the 40 to 99 year age group between 2000 and 2014. A different pattern emerged in Central and South America, where this figure fell to 60% or less.[10] Epidemiological studies show regional variations in incidence trends. A Japanese study found a significant increase in malignant glioma incidence among the elderly between 1998 and 2008.[11] In contrast, CBTRUS data indicated a relatively stable incidence among patients aged ≥40 years between 2000 and 2016.[12] The CONCORD 3 study further reported that the percentage of glioblastoma increased in just two regions from 2000 to 2014, Europe (rising from 46% to 56%) and Oceania (rising from 57% to 65%). A different trend emerged in Central and South America, where glioma NOS became more common. This pattern probably reflects unequal access to cancer registries and restricted quality of neuropathological diagnostics.[10]

Compared to Black and Hispanic populations, non Hispanic White individuals show a markedly greater incidence of glioblastoma and diffuse midline glioma. Such a difference points to a higher prevalence of specific genetic or environmental risk factors within populations of European descent.[7,12] One possible reason for the higher incidence is the growing number of elderly individuals in developed regions like Europe and North America. Other contributing factors include higher socioeconomic status, better access to healthcare systems, and improvements in diagnostic and neuroimaging tools, which enable earlier detection in asymptomatic or mildly symptomatic patients. A rapid yearly increase of 2.9% in glioma incidence occurred between 1978 and 1992 due to these factors. A decline has been observed since 1987, with only a 0.2% annual rise following 1992.[13]

The use of MRI, specifically with T1 weighted, T2 weighted, and gadolinium enhanced sequences, provides a key role in managing gliomas. This encompasses diagnosis, characterization of the tumor, ongoing monitoring, and assessment of therapy. Conventional MRI protocols offer high-resolution, multiplanar structural imaging and superior soft tissue characterization compared to CT. However, MRI signal changes lack biological specificity; for instance, T2-weighted abnormalities largely reflect tissue water content, while contrast enhancement indicates nonspecific disruption of the blood–brain barrier. These limitations reduce the accuracy of non-invasive diagnosis, tumor characterization, and treatment planning, and may complicate the evaluation of active tumor burden due to overlapping treatment-related effects.[14,15]

While contrast enhancement on imaging often points to higher grade lesions, a significant exception exists. Up to 33% of non enhancing gliomas remain malignant despite the lack of enhancement.[15] Contrast enhancement may be visible in several LGG subtypes. Gangliоglioma and pilocytic astrocytoma are examples, along with certain grade 2 oligodendrogliomas[16] and on rare occasions, low grade

astrocytomas.[17] Consequently, contrast enhancement by itself acts as a poor discriminator between high grade and low grade gliomas. When LGG progresses, imaging alterations typically precede a decline in clinical status. In everyday practice, the appearance and increase of focal contrast enhancement are the most common signs indicating tumor progression. These enhancement features are considered more reliable indicators compared to edema, margin characteristics, mass effect, necrosis, or hemorrhage.[18] The exact timing of contrast enhancement appearance during malignant transformation remains uncertain.

The distinction between oligodendroglioma, particularly the type with 1p/19q codeletion, and astrocytoma has major implications for how patients respond to therapy and for their overall prognosis. Compared to astrocytomas, oligodendrogliomas more frequently demonstrate calcifications, cystic features, clear margins, and a tendency to involve the temporal lobe. Primary (de novo) glioblastomas are characterized by amplification of the epidermal growth factor receptor. These primary tumors also tend to have larger enhancing components and less clearly defined borders than secondary glioblastomas, which arise from pre existing low grade gliomas.[19,20]

High grade gliomas in particular display strong heterogeneity, meaning their appearance on imaging and their genetic expression vary widely. These tumors often have poorly defined boundaries. A disrupted blood brain barrier leads to two key findings, namely contrast enhancement and vasogenic edema. However, the extent of active tumor shows limited correspondence with contrast-enhancing regions and T2-weighted edema, which often contain viable tumor cells.[21,22]

In the preoperative phase, advanced MRI techniques serve an important function. For surgical planning, functional MRI (fMRI) is highly beneficial, particularly when tumors are located in or near eloquent brain areas. Many patients who were previously considered unsuitable for surgery due to uncertain neurological outcomes have become candidates for more aggressive resections following functional mapping.[23] Diffusion techniques, including diffusion tensor imaging (DTI), generate white matter tractography that aids neurosurgical planning[24] and helps differentiate postoperative vascular injury from residual tumor.[25] Pharmacokinetic parameters measured by dynamic contrast enhanced (DCE) imaging are linked to both early disease progression and survival outcomes.[26] Dynamic susceptibility contrast (DSC) MRI, on the other hand, aids in the preoperative diagnosis of malignant lesions.[27] Radiomic features derived from both conventional and advanced MRI sequences through computational analysis have demonstrated potential in predicting survival outcomes, molecular subtypes, and mutation status in glioblastoma.[28,29]

Magnetic Resonance Spectroscopy (MRS) allows for the in vivo measurement of neurometabolites in the brain. These measurements are taken from a selected volume of interest (VOI), which can be either a single voxel or multiple voxels. Proper VOI placement is essential to avoid necrotic areas or cerebrospinal fluid and to differentiate infiltrative edema from vasogenic edema. Diffusion weighted imaging (DWI) provides a means of visualizing random Brownian motion as it occurs in water molecules at microscopic dimensions. Water diffusion is normally isotropic. When diffusion is restricted, the affected areas show bright signal on DWI but dark signal on apparent diffusion coefficient (ADC) maps. These findings provide important insights into tissue characteristics, including cellularity, tumor heterogeneity, peritumoral edema, white matter integrity, and treatment-related injury.[30,31] Compared to low grade gliomas, high grade gliomas typically exhibit reduced ADC values. Such low ADC measurements point to higher cell packing and a more malignant course.[32] Increased free water diffusion leads to high ADC measurements in two types of tumor regions. Cystic areas, which are more frequent in LGG, and necrotic areas, which are more frequent in HGG, both demonstrate this pattern.[33]

Comparative Analysis of Conventional and Advanced MRI in Glioma

MRI is the primary imaging modality for diagnosing and grading glioma. Conventional MRI (T1, T2, and FLAIR) visualizes tumor morphology, edema, and surrounding tissue disruption. However, its limitation lies in the inability to assess microstructural and vascular dynamics, which are critical indicators of malignancy. Advanced MRI techniques including DWI, ADC, and DCE-MRI provide functional and molecular parameters that correlate more accurately with glioma grade.[34]

T1-weighted contrast enhancement alone is less accurate for glioma grading compared to advanced techniques such as perfusion imaging, spectroscopy, diffusion imaging, or radiomics analysis. Conventional MRI provides moderate performance: sensitivity of 72.5% and specificity of 65.0% in differentiating high-grade from low-grade gliomas,[35] with reported sensitivity ranging from 55% to over 80%.[25,36]

High-grade gliomas typically show stronger, heterogeneous contrast enhancement, ring-like patterns, necrosis, significant edema, and mass effect. In contrast, low-grade gliomas often show minimal or no enhancement, clearer margins, and less edema.[36,37] However, overlap exists, limiting diagnostic accuracy when relying solely on contrast enhancement.

Advanced MRI provides superior diagnostic value. ADC values from DWI are sensitive and specific for tumor grading, with lower ADC indicating higher cellular density. Perfusion parameters such as Ktrans and AUC reflect tumor angiogenesis. A study in Makassar reported sensitivity of 69% and specificity of 100% for DWI, with significant correlation between ADC values and tumor grade ($p<0.001$).[37,38] Multi-parametric MRI combining conventional and advanced techniques improves non-invasive diagnosis, prognostic evaluation, and clinical management while reducing the need for invasive biopsy.[33]

Studies such as Valentini et al. (2017) demonstrated that rCBV, Cho/Cr, and Cho/NAA ratios correlate significantly with tumor malignancy and proliferation (Ki-67 index), whereas ADC and FA values show less consistency due to tissue heterogeneity.[39] Another study by Seker et al. (2025) showed improved diagnostic accuracy with advanced MRI (sensitivity up to 98% for low-grade glioma).[3] Overall, advanced MRI particularly perfusion (rCBV) and metabolic markers (Cho/Cr, Cho/NAA) serves as a non-invasive biomarker for tumor angiogenesis and proliferation. Integration of these modalities improves diagnostic accuracy and treatment planning.[38]

Advanced MRI parameters also correlate with molecular biomarkers such as IDH mutation, MGMT methylation, and Ki-67, enhancing personalized therapy selection.[40] Artificial intelligence and deep learning approaches using multimodal MRI data have achieved classification accuracy approaching 90% in glioma subtyping.[34]

Research conducted in Indonesia at Cipto Mangunkusumo Hospital from 2015 to 2018 revealed that integrating ADC diffusion parameters with conventional MRI (cMRI) yields better diagnostic performance for differentiating low grade and high grade gliomas than relying solely on cMRI. The combined method achieved a sensitivity of up to 90% and a negative predictive value of 92.9%. This improvement reflects a stronger capacity to rule out high grade malignancies. However, the overall diagnostic accuracy (AUC ~78.6%) remained comparable to individual modalities. These findings support the added value of multiparametric MRI, particularly diffusion imaging, in glioma grading, although the improvement may be modest. This reinforces the need for further studies integrating additional advanced MRI modalities (e.g., perfusion and spectroscopy), as performed in the present study, to enhance diagnostic accuracy and clinical applicability.[40] This study demonstrated that advanced MRI outperforms conventional MRI in grading glioma, with sensitivity 83.3% and specificity 80.6%, compared to 75% and 78.13% for conventional MRI, respectively. Histopathological grading based on WHO classification remains the gold standard; however, advanced MRI significantly supports non-invasive assessment.

The main limitation of this study is that not all histopathological samples underwent molecular testing for IDH mutations. Without molecular analysis, IDH status can only be determined morphologically or via immunohistochemistry, which has lower sensitivity and specificity compared to molecular methods such as PCR or sequencing. Additionally, the study is limited by its sample size, as it uses data from a single hospital within a specific period, resulting in low population diversity and increased risk of selection bias. The absence of multicenter data limits the validity and generalizability of the findings. Furthermore, the use of the same population groups for MRI comparison reduces the strength of the analysis.

CONCLUSION

The assessment of glioma malignancy grade using both conventional and advanced MRI demonstrated a significant correlation with histopathological grading, indicating that these imaging modalities are clinically reliable for evaluating tumor severity. In terms of diagnostic performance, conventional MRI showed an accuracy of 77.3% in determining histopathological grade, while advanced MRI demonstrated a slightly higher accuracy of 81.4%. Nevertheless, the two imaging modalities showed no statistically significant difference when used for glioma grading. This outcome confirms that both conventional and advanced MRI remain clinically useful for the noninvasive assessment of glioma malignancy. The authors advise additional research to explore how these techniques perform across a wider range of brain tumors beyond just gliomas. Additionally, future research should explore their use in tumors outside the central nervous system, with comparisons to histopathological results. Larger studies involving more diverse populations, including different racial and geographic groups, are necessary to enhance the validity and generalizability of the findings. Finally, incorporating molecular analyses,

particularly the detection of IDH mutations, is recommended to improve diagnostic accuracy and tumor classification in accordance with the WHO 2021 guidelines for glioma management.

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