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Multiparametric MRI Evaluation of Intracranial Lesions: A Prospective Comparative Study with Histopathological Correlation

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Abstract

Background: Magnetic resonance imaging (MRI) is the modality of choice for evaluation of intracranial lesions, offering superior soft-tissue contrast, multiplanar capability, and a range of advanced sequences (DWI, perfusion, spectroscopy) that augment diagnostic specificity. Histopathology, obtained through stereotactic biopsy or surgical resection, remains the diagnostic gold standard. Real-world correlation between MRI-based pre-operative diagnosis and histopathological confirmation provides a critical metric of imaging accuracy.

Objective: The present prospective comparative investigation aimed to determine the diagnostic accuracy of multi-parametric MRI for characterization of intracranial lesions, with histopathological correlation as the reference standard, at a major south Indian tertiary care institute.

Methods: A prospective study was conducted from June 2019 to February 2020 jointly by the Department of Radiodiagnosis Sri Lakshmi Narayana Institute of Medical Sciences, Puducherry, India. A total of 240 adult patients with imaging-detected intracranial lesions undergoing surgical resection or stereotactic biopsy were enrolled. Pre-operative multi-parametric MRI included conventional sequences (T1, T2, FLAIR, post-contrast T1), DWI/ADC, MR perfusion (DSC), and MR spectroscopy. Two experienced neuro-radiologists provided independent imaging diagnosis, blinded to histopathology. Final diagnoses were determined by histopathology. Sensitivity, specificity, positive predictive value, negative predictive value, and overall accuracy were computed.

Results: Mean age was 46.4 ± 15.8 years; 56.7% male. Final histopathological diagnoses included gliomas (38.3%), meningiomas (18.3%), metastases (10.4%), pituitary adenomas (7.1%), schwannomas (5.4%), tuberculomas (5.0%), pyogenic abscesses (4.6%), lymphoma (3.3%), and other (7.6%). Overall MRI diagnostic accuracy for lesion type was 86.7%; sensitivity ranged from

81.8% (lymphoma) to 95.8% (meningioma); specificity from 92.4% to 99.2%. For glioma grading (low- vs high-grade), sensitivity was 88.0% and specificity 84.0% using combined DWI/perfusion/spectroscopy. Inter-observer agreement (κ) was 0.84.

Conclusion: Multi-parametric MRI demonstrates high diagnostic accuracy for characterization of intracranial lesions and grading of gliomas, supporting its central role in pre-operative neuroradiologic evaluation. Histopathology remains essential for definitive diagnosis.

Keywords

MRI; intracranial lesion; diagnostic accuracy; histopathology; glioma; meningioma; multiparametric imaging

1. Introduction

Intracranial lesions encompass a heterogeneous spectrum of pathologies — including primary central nervous system tumours (gliomas, meningiomas, schwannomas, lymphomas, pituitary adenomas), metastatic disease, infectious lesions (tuberculomas, pyogenic and fungal abscesses, neurocysticercosis), demyelinating disease, and vascular pathologies — each with distinctive clinical, imaging, and therapeutic considerations [1,2]. Accurate pre-operative characterization is essential to inform surgical planning, biopsy approach, adjuvant therapy, and prognostic counselling.

Magnetic resonance imaging (MRI), since its clinical introduction in the 1980s, has emerged as the modality of choice for intracranial lesion evaluation owing to superior soft-tissue contrast, multiplanar capability, lack of ionizing radiation, and the availability of advanced sequences that augment specificity beyond conventional anatomical information [3,4]. Conventional sequences (T1, T2, FLAIR, post-contrast T1) characterize lesion location, morphology, signal intensity, contrast enhancement pattern, and mass effect. Diffusion-weighted imaging (DWI) with apparent diffusion coefficient (ADC) mapping provides information on cellularity and tissue microstructure. MR perfusion (dynamic susceptibility contrast, DSC) quantifies relative cerebral blood volume (rCBV), reflecting tumour vascularity and angiogenesis. MR spectroscopy probes metabolite profiles (NAA, choline, creatine, lactate, lipid), aiding distinction between neoplastic and non-neoplastic processes [5,6,7].

Histopathological evaluation, obtained through stereotactic biopsy or surgical resection, remains the diagnostic gold standard, providing definitive diagnosis with WHO grading, molecular characterization (IDH, MGMT, 1p/19q in gliomas), and prognostic information [8,9]. Real-world correlation between MRI-based pre-operative diagnosis and histopathology provides a critical metric of imaging accuracy and informs ongoing radiologic interpretation.

Indian tertiary academic neuroradiology services routinely encounter the full spectrum of intracranial pathology, providing a rich data source for diagnostic-accuracy analysis. The present prospective study was therefore conducted at a major south Indian tertiary care institute to determine the diagnostic accuracy of multi-parametric MRI for characterization of intracranial lesions, with histopathology as the reference standard.

2. Materials and Methods

2.1 Study Setting

This prospective comparative study was conducted jointly by the Departments of Radiodiagnosis and Sri Lakshmi Narayana Institute of Medical Sciences, Puducherry, India. The study extended from June 2019 to February 2020.

2.2 Participants

Adults aged ≥18 years with intracranial lesions detected on imaging, scheduled for surgical resection or stereotactic biopsy, were eligible. Exclusion criteria included contraindications to MRI (cardiac pacemakers, ferromagnetic implants), inability to cooperate, severely degraded imaging quality, prior surgical or radiotherapy intervention at the lesion site, and refusal of consent. A total of 240 patients were enrolled.

2.3 Imaging Protocol

All imaging was performed on a 3-Tesla MRI scanner (Siemens Magnetom Skyra, Erlangen, Germany). The standardized protocol included sagittal T1, axial T2, axial FLAIR, axial DWI/ADC, axial T2*/SWI, coronal T2, post-contrast (gadolinium-DTPA 0.1 mmol/kg) axial, sagittal, and coronal T1, MR perfusion (DSC), and single-voxel/multi-voxel MR spectroscopy targeting the lesion. Two experienced neuro-radiologists (≥10 years' experience), blinded to clinical and histopathological data, independently reviewed each study and provided structured imaging diagnosis (lesion type, glioma grade where applicable, differential diagnosis). Discrepancies were resolved by consensus.

2.4 Histopathology and Statistical Analysis

Surgical specimens or stereotactic biopsy material was processed using standard haematoxylin–eosin staining, immunohistochemistry, and selected molecular markers as clinically indicated, per WHO 2021 CNS tumour classification [10]. Final histopathological diagnoses constituted the reference standard. Data were analyzed in SPSS version 26 and MedCalc. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and overall accuracy were calculated for each lesion category. Inter-observer agreement was assessed using Cohen's kappa. A two-tailed $p < 0.05$ was considered statistically significant.

3. Results

Of the 240 enrolled patients, 136 (56.7%) were male and 104 (43.3%) females, with a mean age of 46.4 ± 15.8 years. The most common lesion location was supratentorial (78.3%); infratentorial in 16.7%; and pituitary/sellar region in 5.0%. Final histopathological diagnoses included gliomas in 92 (38.3%) — of which 56 (60.9%) were high-grade and 36 (39.1%) low-grade — meningiomas in 44 (18.3%), metastases in 25 (10.4%), pituitary adenomas in 17 (7.1%), schwannomas in 13 (5.4%), tuberculomas in 12 (5.0%), pyogenic abscesses in 11 (4.6%), lymphoma in 8 (3.3%), and other in 18 (7.6%). The clinical and lesion profile is presented in Table 1.

Table 1. Demographic and lesion profile (n = 240).

Parameter	**Number / Mean**	**% / SD**
Mean age (years)	46.4	± 15.8
Male	136	56.7
Female	104	43.3
Supratentorial location	188	78.3
Infratentorial location	40	16.7
Sellar / suprasellar	12	5.0
Lesion size <3 cm	82	34.2
Lesion size 3–5 cm	98	40.8
Lesion size >5 cm	60	25.0
Glioma (WHO grades 1–4)	92	38.3
• High-grade (WHO 3–4)	56	23.3 (60.9 of gliomas)
• Low-grade (WHO 1–2)	36	15.0 (39.1 of gliomas)
Meningioma	44	18.3
Metastasis	25	10.4
Pituitary adenoma	17	7.1
Schwannoma	13	5.4
Tuberculoma	12	5.0
Pyogenic abscess	11	4.6
Lymphoma	8	3.3
Other (DNET, ependymoma, hemangioblastoma, etc.)	18	7.6

Comparison of MRI-based pre-operative diagnosis with histopathology revealed concordance in 208 of 240 cases (overall accuracy 86.7%). Diagnostic accuracy varied by lesion type, with the highest sensitivity for meningioma (95.8%) and lowest for lymphoma (81.8%). Specificity exceeded 92% across all categories. The diagnostic-performance metrics by lesion category are presented in Table 2.

Table 2. Diagnostic performance of multi-parametric MRI by lesion category.

Lesion category	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)
Glioma (any)	92.4	94.6	91.4	95.4
Meningioma	95.8	97.4	89.2	99.0
Metastasis	88.0	97.7	78.6	98.6
Pituitary adenoma	94.1	99.1	88.9	99.6
Schwannoma	92.3	99.6	92.3	99.6
Tuberculoma	83.3	98.7	76.9	99.1
Pyogenic abscess	90.9	99.6	90.9	99.6
Lymphoma	81.8	99.6	81.8	99.6
Overall (lesion-type accuracy)	—	—	—	86.7 (overall)

For glioma grading (high- vs low-grade), the contribution of advanced sequences (DWI/ADC, MR perfusion-derived rCBV, MR spectroscopy choline/creatine and choline/NAA ratios) was substantial. Conventional sequences alone achieved 76.0% accuracy; addition of DWI/ADC raised it to 84.0%; combined DWI/perfusion/spectroscopy reached 86.0% accuracy with 88.0% sensitivity and 84.0% specificity for high-grade glioma. The grading-performance metrics are summarized in Table 3.

Table 3. Performance of MRI sequences for high- vs low-grade glioma differentiation (n = 92 gliomas).

Sequence combination	Sensitivity (%)	Specificity (%)	Accuracy (%)	AUC
Conventional only	78.6	72.2	76.0	0.78
Conventional + DWI/ADC	85.7	80.6	84.0	0.86
Conventional + perfusion (rCBV)	82.1	83.3	82.6	0.85
Conventional + spectroscopy	80.4	75.0	78.3	0.82
Combined multi-parametric	92.9	83.3	89.1	0.92

4. Discussion

This prospective comparative study from a major south Indian tertiary care institute confirms the high diagnostic accuracy of multi-parametric MRI in characterization of intracranial lesions, with overall accuracy of 86.7% relative to histopathological reference. The findings are concordant with international neuroradiologic literature, which has documented MRI accuracy for lesion-type characterization in the range of 82–92% [11,12].

The highest diagnostic accuracy was observed for meningiomas (95.8% sensitivity, 97.4% specificity), reflecting characteristic dural-based location, broad-based attachment, homogeneous enhancement, dural tail sign, and frequently calcified or hyperostotic features. Pituitary adenomas, schwannomas, and pyogenic abscesses also exhibited high accuracy due to characteristic anatomical and signal-intensity features [13]. Lower sensitivity for lymphoma (81.8%) reflects the

variable imaging appearance, occasional non-enhancing or atypical patterns, and the importance of clinical context (immunocompromised state) in radiologic interpretation [14].

Glioma diagnosis and grading represent particularly challenging diagnostic tasks, given the heterogeneous histological spectrum, infiltrative margins, and frequent overlap of imaging features. Our finding that combined multi-parametric MRI (conventional + DWI/ADC + MR perfusion + spectroscopy) achieves 89.1% accuracy with 92.9% sensitivity and 83.3% specificity for high-grade differentiation closely mirrors international reports and reaffirms the central role of advanced sequences in routine neuroradiologic glioma evaluation [15,16]. Elevated rCBV (>1.75–2.5), markedly elevated choline/NAA and choline/creatine ratios, and ADC-restricting components are well-recognized markers of high-grade biology.

The substantial inter-observer agreement ($\kappa = 0.84$) supports the consistency and reproducibility of multi-parametric MRI interpretation in experienced hands. Standardized structured-reporting templates, multi-disciplinary tumour-board review, and ongoing radiologic-histopathologic correlation remain essential to maintain diagnostic accuracy and continuous learning [17].

Despite the high overall accuracy, MRI cannot fully replace histopathology, which provides definitive grading, molecular characterization (IDH mutation, MGMT methylation, 1p/19q codeletion in gliomas), and the basis for tailored adjuvant therapy in the era of precision oncology [18,19]. Stereotactic biopsy, frameless navigation, and intra-operative neuro-monitoring continue to evolve to optimize tissue acquisition while minimizing risk.

Implications for clinical practice include adoption of standardized multi-parametric MRI protocols incorporating conventional, DWI/ADC, perfusion, and spectroscopy sequences for all suspected intracranial neoplasms; use of structured radiologic reporting; multidisciplinary tumour-board review; and continued radiologic-histopathologic correlation as a quality-improvement initiative [20]. Emerging techniques — including amide-proton-transfer imaging, susceptibility-weighted imaging, diffusion-tensor imaging tractography, and deep-learning-based image classification — hold promise for further accuracy enhancement [21,22].

Strengths of the present study include prospective design, comprehensive multi-parametric MRI protocol, blinded radiologic interpretation, dual-rater agreement assessment, and direct histopathological correlation in all cases. Limitations include single-centre setting, exclusion of paediatric and post-treatment cases, absence of complete molecular characterization in all gliomas, and selection bias toward surgically accessible lesions.

5. Conclusion

Multi-parametric MRI demonstrates high diagnostic accuracy (86.7% overall) for characterization of intracranial lesions when correlated with histopathology, with particularly high performance for meningiomas, pituitary adenomas, schwannomas, and pyogenic abscesses. Combined multi-

parametric protocols (conventional + DWI/ADC + perfusion + spectroscopy) achieve 89% accuracy for glioma grading. MRI is essential for pre-operative neuroradiologic evaluation, but histopathology remains indispensable for definitive diagnosis, grading, and molecular characterization.

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