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Original Research Paper

Radio-Diagnosis

THE ROLE OF DIFFUSION WEIGHTED IMAGING AND MR SPECTROSCOPY IN RING ENHANCING BRAIN LESIONS SEEN ON MAGNETIC RESONANCE IMAGING

Dr Pramod Sakhi Professor, Department Of Radiodiagnosis, Sri Aurobindo Medical College & PG Institute, Indore (M.P).

Dr Pranshul Gupta* PG Resident, Department Of Radiodiagnosis, Sri Aurobindo Medical College & PG Institute, Indore (M.P). *Corresponding Author

Dr Deepal Nema PG Resident, Department Of Radiodiagnosis, Sri Aurobindo Medical College & PG Institute, Indore (M.P).

ABSTRACT

Background: Ring-enhancing lesions (RELs) pose a significant diagnostic challenge due to their varied etiologies, including infections, neoplasms, and demyelinating disorders. In regions like India, tuberculoma and neurocysticercosis (NCC) are commonly encountered. While MRI provides detailed anatomy, it often lacks specificity. Advanced techniques like DWI and MRS enhance diagnostic accuracy by revealing diffusion and metabolic characteristics. The present study aimed to evaluate and compare the diagnostic performance of MRI, DWI, and MRS in characterizing intracranial RELs. **Materials And Methods:** This prospective observational study included 50 patients with RELs identified on MRI, conducted over 18 months at a tertiary care centre. All patients underwent MRI with DWI and single-voxel MRS. Final diagnosis was based on histopathology or clinical follow-up. Imaging findings were analyzed using standard statistical methods. **Results:** Tuberculomas (36%) were the most common lesions, followed by metastases (22%), NCC (18%), abscesses (10%), and primary tumors (10%). MRS identified lipid/lactate peaks in 94.4% of tuberculomas, succinate/acetate in 88.9% of NCC, and elevated amino acids in 80% of abscesses. Metastases showed high choline/creatine ratios in 90.9%. DWI detected diffusion restriction in 80% of abscesses and tumors. MRI+MRS showed the highest diagnostic accuracy (96%) compared to MRI alone (84–88%) or MRI+DWI (90–92%). Significant associations were observed between lesion type and age ($p = 0.039$), lesion number ($p = 0.016$), and diffusion restriction ($p = 0.005$). **Conclusion:** MRI with DWI and MRS significantly improves non-invasive diagnostic accuracy for RELs, aiding early and accurate differentiation between infectious and neoplastic causes.

KEYWORDS : Ring-enhancing lesions, Tuberculoma, Magnetic Resonance Spectroscopy, Diffusion-Weighted Imaging, Neurocysticercosis.

INTRODUCTION

Ring-enhancing lesions (REL) are among the most frequently encountered abnormalities in neuroimaging and pose a considerable diagnostic challenge due to their association with a diverse spectrum of pathological conditions. These lesions are defined by their characteristic contrast-enhancing ring on imaging, a feature that typically results from blood-brain barrier disruption and the formation of an inflammatory or fibrotic capsule. [1,2] RELs are observed in a variety of clinical scenarios, including infectious, neoplastic, inflammatory, and demyelinating diseases, making their accurate identification and differentiation imperative for effective clinical management. [3]

Globally, gliomas account for the highest proportion of RELs (40%), followed by metastatic tumors (30%), brain abscesses (8%), and multiple sclerosis (6%). [4] In contrast, studies from the Indian subcontinent report a predominance of infectious causes, with tuberculomas representing nearly 46.6% of RELs, followed by glioblastoma multiforme (20%), metastases (13.3%), and abscesses (10%) .[5,6] This disparity highlights the influence of geographic epidemiology, with tuberculosis being a major contributor to RELs in endemic regions such as India.

Clinically, RELs often present with persistent seizures, focal neurological deficits, and signs of raised intracranial pressure such as headache, vomiting, and papilledema. In advanced cases, cerebral edema may lead to altered consciousness and herniation syndromes. [7] Neuroimaging plays a vital role in the diagnosis of these lesions. While CT remains a commonly used initial modality due to its accessibility and speed, it has limitations in sensitivity and anatomical resolution, particularly in the posterior fossa and white matter diseases. [8]

MRI, owing to its superior contrast resolution and multiplanar capabilities, has become the gold standard in the evaluation of RELs, detecting more than 90% of brain lesions compared to 77% with CT. [9-11] However, conventional MRI often falls short in distinguishing between neoplastic and non-neoplastic lesions. [12,13] To overcome this, advanced modalities such as Diffusion-Weighted Imaging (DWI), perfusion imaging, and Proton Magnetic Resonance Spectroscopy (^{1}H-MRS) have been integrated into clinical practice to enhance diagnostic specificity. [12]

MRS provides metabolic insights by quantifying in vivo concentrations of key brain metabolites, thus enabling distinction between conditions such as tuberculoma, neurocysticercosis, and neoplasms. [13] This study investigates the diagnostic role of MRI and MRS in characterizing RELs, particularly focusing on their utility in distinguishing infectious from neoplastic etiologies, thereby improving diagnostic accuracy and clinical decision-making.

MATERIAL AND METHOD

This hospital-based prospective, observational, cross-sectional study was conducted in the Department of Radiodiagnosis at Sri Aurobindo Medical College and Post Graduate Institute, Indore, over a period of 18 months, from 1st June 2023 to 30th November 2024. A total of 50 patients of varying age and gender, presenting with clinical suspicion of intracranial space-occupying lesions showing ring enhancement on imaging, were enrolled. The study received ethical clearance from the Institutional Ethics and Research Committee. Written informed consent was obtained from all participants or their legal guardians. Ethical principles, including respect for patient autonomy, confidentiality, and the right to withdraw from the study at any time, were strictly followed.

Inclusion Criteria

- Patients of any age and gender presenting with ring-

enhancing lesions on MRI brain.
- Patients who underwent both Diffusion Weighted Imaging (DWI) and Magnetic Resonance Spectroscopy (MRS).
- Patients with confirmed diagnosis through histopathology or clinical follow-up after treatment.

Exclusion Criteria
- Patients who declined to participate.
- Patients lost to follow-up or with incomplete imaging
- Patients with contraindications to MRI (e.g., pacemakers, metallic implants).

Imaging Protocol
All MRI studies were performed using either a 1.5 Tesla Siemens Magnetom® Symphony® or a 3 Tesla Siemens Magnetom Vida MRI scanner. The imaging protocol included - Conventional MRI sequences: axial T1-weighted, T2-weighted, FLAIR; coronal and sagittal T2-weighted; and post-contrast axial T1-weighted images, Diffusion Weighted Imaging (DWI) for assessment of diffusion characteristics, Magnetic Resonance Spectroscopy (MRS): Single-voxel MRS was performed with TE = 144 ms. The voxel was strategically placed to cover the lesion's core and its immediate margin while avoiding bony structures and ventricles to reduce artifacts. MRS spectra were analyzed for metabolites such as choline (Cho), creatine (Cr), N-acetylaspartate (NAA), lactate, lipids, and amino acids.

Procedure
After clinical evaluation and informed consent, all patients underwent MRI brain with DWI and MRS. Imaging findings were interpreted independently by experienced radiologists blinded to the clinical diagnosis. Final diagnosis was established based on histopathological examination (biopsy or surgical excision) or, in medically managed cases, on clinical resolution and therapeutic response.

Data Collection And Analysis
Data were documented using a structured proforma and compiled in Microsoft Excel 2010. Statistical analysis was performed using IBM SPSS Statistics version 26.0. Descriptive statistics summarized demographic and clinical variables. Diagnostic performance (sensitivity, specificity, PPV, NPV, and accuracy) of DWI, MRS, and their combination was assessed against the final diagnosis. A p-value < 0.05 was considered statistically significant.

RESULTS
The demographic analysis of the study population showed a balanced age distribution, The mean age was 38.62 ± 14.87 years, reflecting a middle-aged predominance. Males comprised 54% and females 46%.

Multiple lesions were observed in 62% of patients, while 38% had solitary lesions. Supratentorial location was most common (60%), followed by both compartments (22%) and infratentorial alone (18%). Mild (40%) and moderate edema (32%) were most frequent. [Table 1] Seizures and headache with seizures were the most common clinical presentations (18% each), followed by headache (16%) and headache with fever (12%). Less frequent symptoms included headache with ataxia (6%), fever with seizure (6%), and focal neurological deficits (≤4%).

Table 1: Demographic, Clinical, And Radiological Profile Of The Study Population (N = 50)

Parameter	Category	Number of Patients	Percent (%)
Number of Lesions	Single	19	38.0
	Multiple	31	62.0
Lesion Location	Supratentorial	30	60.0
	Infratentorial	9	18.0
	Both Regions	11	22.0
Perilesional Edema	Minimal	11	22.0
	Mild	20	40.0
	Moderate	16	32.0
	Severe	3	6.0

Magnetic Resonance Spectroscopy (MRS) proved to be a valuable non-invasive modality for characterizing ring-enhancing lesions (RELs). Tuberculomas (36%) exhibited lipid/lactate peaks in 94.4% of cases, while NCC (18%) showed lactate, succinate, or acetate peaks in 88.9%. Brain abscesses demonstrated elevated amino acids in 80% of cases. Neoplastic lesions metastases (22%) and primary brain tumors (10%) consistently showed high choline/creatinine ratios, with lipid/lactate peaks present in 90.9% of metastases. Infectious etiologies constituted 66% of all cases. MRS significantly enhanced diagnostic accuracy by detecting lesion-specific metabolic profiles, enabling reliable differentiation between infections and neoplasms, and minimizing reliance on invasive diagnostics. [Table 2]

Table 2. MR Spectroscopic, And Diagnostic Profile Of Patients With Ring-Enhancing Lesions (N = 50)

Parameter	Category	Number of Patients	Percent (%)
MRS Characteristics by Final Diagnosis	Tuberculoma – Lipid/Lactate peak	17/18	94.4 %
	NCC – Elevated Lactate/Succinate/Acetate	8/9	88.9 %
	Abscess – Elevated Amino Acids	4/5	80.0 %
	Primary Tumor – High Cho/Cr ratio	4/5	80.0 %
	Metastasis – High Cho/Cr & Lipid/Lactate	10/11	90.9 %
Final Diagnosis (Lesion Type)	Tuberculoma	18	36.0
	Metastasis	11	22.0
	Neurocysticercosis (NCC)	9	18.0
	Abscess	5	10.0
	Primary Brain Tumor	5	10.0
	Toxoplasmosis	1	2.0
	Demyelination	1	2.0

In this study of 50 patients with ring-enhancing lesions (RELs), several statistically significant associations were identified. A significant correlation was found between age group and lesion type ($p = 0.039$), with tuberculomas most frequent in the 10–20 years group (27.8%) and NCC in the 20–30 years group (55.6%), while metastases (36.4%) and brain tumors (80%) were predominant in patients aged ≥50 years. Lesion multiplicity also showed a significant association ($p = 0.016$), with multiple lesions observed in tuberculomas (83.3%), metastases (72.7%), and demyelination (100%), whereas all primary tumors were solitary (100%). Diffusion restriction on DWI was significantly associated with lesion type ($p = 0.005$), being present in 80% of abscesses and tumors, 63.6% of metastases, but only 11.1% of tuberculomas and 22.2% of NCC cases [Table 3] . Other variables such as sex ($p = 0.784$), anatomical location ($p = 0.620$), and edema severity ($p = 0.114$) showed no statistically significant correlation with lesion type.

In this study, MRI characteristics proved instrumental in differentiating various ring-enhancing lesions In this study of ring-enhancing brain lesions (RELs), distinct imaging patterns aided in differentiating various etiologies. Among the five brain abscess cases, 80% (4/5) showed restricted diffusion on DWI typical of purulent content and all were hyperintense on T2-weighted images. Tuberculomas (n = 18) demonstrated T2 hypointensity in 56% and lacked diffusion restriction in 89% (16/18), helping distinguish them from abscesses. Thick ring enhancement was seen in 61% of tuberculomas. Metastases

(n = 11) were T2 hyperintense in 82%, showed diffusion restriction in 64%, and had irregular thick rim enhancement in 73%. Neurocysticercosis (n = 9) commonly exhibited T2 hyperintensity (78%) and lacked diffusion restriction (78%), with most cases showing thin or regular rim enhancement. Both glioblastoma cases demonstrated restricted diffusion and nodular ring enhancement (100%), while demyelination and toxoplasmosis presented without diffusion restriction but with classic enhancement patterns open-ring and eccentric rim, respectively

Table 3. Association Between Type of Intracranial Ring-Enhancing Lesions and Demographic, Clinical, and Imaging Variables with p-values (N = 50)

Parameter	Subgroup	Tuberculoma (n=18)	NCC (n=9)	Abscess (n=5)	Metastasis (n=11)	Primary Tumor (n=5)	Total (%)
Age Group	10–20 yrs	5 (27.8%)	3 (33.3%)	0 (0%)	0 (0%)	0 (0%)	8 (16.0%)
	20–30 yrs	2 (11.1%)	5 (55.6%)	2 (40%)	0 (0%)	0 (0%)	9 (18.0%)
	30–40 yrs	3 (16.7%)	1 (11.1%)	2 (40%)	2 (18.2%)	0 (0%)	9 (18.0%)
	40–50 yrs	2 (11.1%)	0 (0%)	1 (20%)	2 (18.2%)	2 (40%)	8 (16.0%)
	50–60 yrs	2 (11.1%)	0 (0%)	0 (0%)	3 (27.3%)	2 (40%)	7 (14.0%)
	≥60 yrs	4 (22.2%)	0 (0%)	0 (0%)	4 (36.4%)	1 (20%)	9 (18.0%)
No. of Lesions	Multiple	15 (83.3%)	4 (44.4%)	2 (40%)	8 (72.7%)	0 (0%)	31 (62.0%)
	Single	3 (16.7%)	5 (55.6%)	3 (60%)	3 (27.3%)	5 (100%)	19 (38.0%)
Diffusion Restriction	Present	2 (11.1%)	2 (22.2%)	4 (80%)	7 (63.6%)	4 (80%)	19 (38.0%)
	Absent	16 (88.9%)	7 (77.8%)	1 (20%)	4 (36.4%)	1 (20%)	31 (62.0%)

Restricted diffusion was most associated with abscesses (80%) and high-grade tumors (100%), while tuberculomas (11%) and NCC (22%) rarely exhibited it. T2 hypointensity was more indicative of tuberculomas (56%) than NCC (22%). Thick, irregular enhancement was typical of metastases and tuberculomas. These imaging features, especially when integrated with DWI and clinical findings, significantly improve the non-invasive diagnostic precision for RELs.

The combined diagnostic analysis confirms that MRI+MRS consistently outperforms conventional MRI and MRI+DWI across all lesion types, offering superior sensitivity, specificity, PPV, NPV, and overall accuracy. For tuberculomas, sensitivity increased from 72.2% with MRI alone to 94.4% with MRI+MRS, and overall accuracy improved from 84.0% to 96.0%. In NCC, specificity rose from 90.2% to 97.6% with the addition of MRS. Brain abscesses showed a significant jump in sensitivity from 40% (MRI) to 80% (MRI+MRS), with an NPV of 97.8%, reducing false negatives.

Metastases and primary tumors also showed marked improvement with MRS, achieving sensitivity and specificity above 90%, compared to 40–72.7% sensitivity using MRI alone. While MRI+DWI enhanced diagnostic performance over MRI alone, MRI+MRS yielded the highest diagnostic precision across all parameters, closely approximating histopathological confirmation.

These findings underscore the importance of integrating advanced techniques like DWI and especially MRS into routine imaging for accurate, non-invasive characterization of RELs, especially in distinguishing between infectious and neoplastic lesions. [Table 4]

Table 4. Comparative Diagnostic Performance of MRI, MRI+DWI, and MRI+MRS versus Histopathology for Intracranial Lesions

MRI Findings V/S Histopathology					
Lesion	**Sensitivity**	**Specificity**	**PPV**	**NPV**	**Accuracy**
TUBERCULOMAS	72.2%	90.6%	81.3%	85.3%	84.0%
NCC	66.7%	90.2%	60.0%	92.5%	86.0%
Abscess	40.0%	88.9%	28.6%	93.0%	84.0%
Metastasis	72.7%	92.3%	72.7%	92.3%	88.0%
Primary Brain Neoplasia	40.0%	93.3%	40.0%	93.3%	88.0%
MRI +DWI Findings					
Lesion	**Sensitivity**	**Specificity**	**PPV**	**NPV**	**Accuracy**
Tuberculomas	83.3%	93.8%	88.2%	90.9%	90.0%
NCC	77.8%	95.1%	77.8%	95.1%	92.0%
Abscess	80.0%	93.3%	57.1%	97.7%	92.0%
Metastasis	81.8%	94.9%	81.8%	94.9%	92.0%
Primary Brain Neoplasia	60.0%	95.6%	60.0%	95.6%	92.0%
MRI+MRS V/S HISTOPATHOLOGY					
Lesion	**Sensitivity**	**Specificity**	**PPV**	**NPV**	**Accuracy**
Tuberculomas	94.4%	96.9%	94.4%	96.9%	96.0%
NCC	88.9%	97.6%	88.9%	97.6%	96.0%
Abscess	80.0%	97.8%	80.0%	97.8%	96.0%
Metastasis	90.9%	97.4%	90.9%	97.4%	96.0%
Primary Brain Neoplasia	80.0%	97.8%	80.0%	97.8%	96.0%

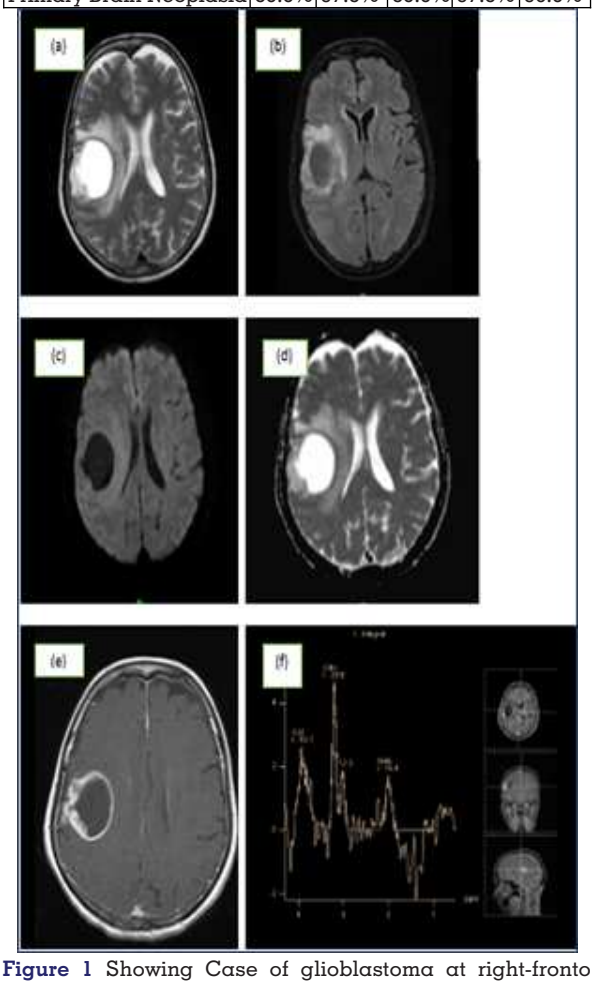

Figure 1 Showing Case of glioblastoma at right-fronto parietal lobe. (a, b) Predominantly cystic/necrotic mass lesion is seen at the parieto-frontal lobe, on T-2 and FLAIR imaging. (c, d) No restriction diffusion noted in the mass lesion. (e)Thick nodular peripheral enhancement is noted on post contrast imaging. (f) MR spectroscopy findings reveal increased choline and elevated choline/creatinine ratio

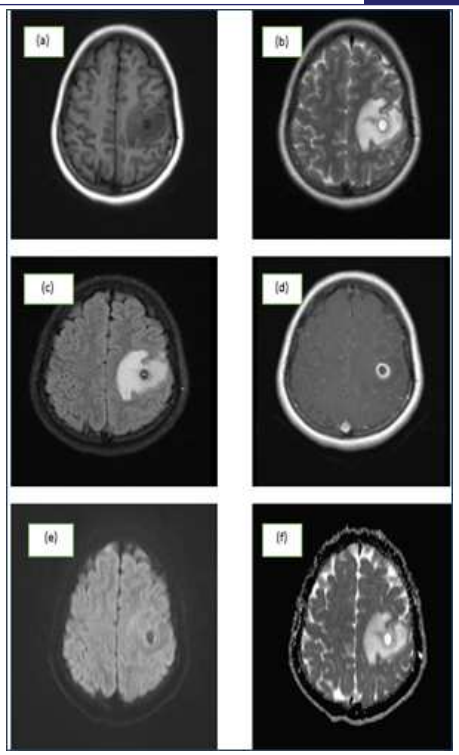

Figure 2 Showing Case of Neurocysticercosis at left frontal lobe. (a, b) The lesion appears T1 hypointense and T2 hyperintense with perilesional edema seen. (c) Fluid-attenuated inversion recovery sequence shows eccentric mural nodule representing scolex. (d) Post contrast imaging shows smooth peripheral ring enhancing lesion. (e, f) No restricted diffusion is seen within the lesion

DISCUSSION

Ring-enhancing brain lesions (RELs) present a diagnostic challenge due to diverse causes including infections, demyelination, and tumors. In endemic areas like India, infections such as tuberculoma and NCC are common. While MRI offers anatomical detail, advanced techniques like DWI and MRS enhance diagnostic accuracy through diffusion and metabolic characterization.

In our study of 50 patients, tuberculoma emerged as the most common etiology (36%), followed by metastases (22%), NCC (18%), brain abscesses and primary tumors (10% each), and others (4%). These findings align with previous Indian studies, including those by Nandan Kumar L.D. et al. (2024) [14] and Bava JS et al. (2016), [10] reaffirming the high prevalence of infectious etiologies in tuberculosis-endemic areas. Demographically, younger adults (20–40 years) were more commonly affected by infections, while neoplastic lesions were seen more frequently in patients over 50 years. A mild male predominance was observed, consistent with findings by Ram H et al. (2023) [15] and Elsadway ME et al. (2020). [2]

Clinically, the most frequent symptoms were seizures (18%) and headache with seizures (18%), followed by isolated headache (16%). These results are in agreement with earlier studies by Mahato PS et al. (2012) [5] and Ram H et al. (2023) [15], suggesting that RELs frequently present with non-specific neurological symptoms, further reinforcing the importance of advanced imaging for accurate etiological differentiation.

DWI proved especially useful in diagnosing abscesses, with 80% (4/5) of cases showing diffusion restriction a hallmark of purulent content. This finding is consistent with earlier reports by Mishra AM et al. (2004) [16], Reddy JS et al. (2006) [17], and Alam MS et al. (2012) [18], who highlighted restricted diffusion as a key identifier for abscesses. However, in cases where diffusion restriction was absent or ambiguous, MRS provided critical diagnostic clarity.

MRS significantly enhanced diagnostic confidence by detecting lesion-specific metabolite patterns. Tuberculomas exhibited lipid and lactate peaks in 94.4% of cases indicative of granulomatous inflammation and necrosis. These patterns corroborate findings from Seth S et al. (2017) [19], and Verma SR et al. (2017) [20], and helped distinguish tuberculomas from NCC and neoplasms. NCC, by contrast, showed succinate/acetate peaks in 88.9% of cases, without lipid peaks findings supported by Kumar A et al. (2003) [21] and Anand AM et al. (2023) [22].

Metastatic lesions and high-grade primary tumors such as glioblastoma were identified based on elevated choline, decreased NAA, and increased Cho/Cr and Cho/NAA ratios. Metastases often also showed lipid-lactate peaks (90.9%) due to necrosis. These MRS signatures align with studies by Brandao LA, Elmoneim BA et al. (2016) [23], and Jain A et al. (2018) [24]. MRS achieved 90.9% sensitivity and 96% diagnostic accuracy for metastases in our cohort. Similarly, glioblastoma multiforme demonstrated classic MRS findings marked choline elevation and NAA suppression which closely mirrored the patterns reported by Solanki RN et al. (2017) [25] and Ram H et al. (2023) [15].

Less common lesions like demyelination and toxoplasmosis also demonstrated distinctive imaging traits. The demyelinating lesion showed open-ring enhancement and mild choline elevation without diffusion restriction, consistent with findings from Maheshwarappa RP et al. (2019) [26]. Toxoplasmosis exhibited eccentric ring enhancement and a neutral metabolic profile on MRS, helping rule out neoplasms and pyogenic abscesses.

Overall, the combined use of MRI, DWI, and MRS markedly improved diagnostic accuracy across lesion types. MRI alone yielded moderate sensitivity (66–72%), which increased with the addition of DWI (78–83%) and peaked with MRI+MRS (88–96%). MRS notably improved differentiation between infectious and neoplastic lesions, often approaching the diagnostic reliability of histopathology, as supported by Solanki RN et al. (2017) [27].

Despite offering valuable insights, this single-center study with 50 patients had limitations, including small sample size, lack of long-term follow-up, and incomplete histopathological confirmation. Inter-observer variability in MRS interpretation may have affected accuracy. Future multi-center, AI-integrated studies with standardized protocols and follow-up are recommended for improved diagnostic precision.

CONCLUSION

In conclusion, this study highlights the critical diagnostic value of combining Diffusion-Weighted Imaging (DWI) and Magnetic Resonance Spectroscopy (MRS) with conventional MRI in evaluating ring-enhancing intracranial lesions. The integrated approach significantly improves diagnostic accuracy by distinguishing infectious, neoplastic, and inflammatory pathologies with overlapping imaging features. Tuberculomas, NCC, and metastases were the most common etiologies, with distinct clinical and radiological patterns effectively identified using DWI and MRS. These modalities enhanced sensitivity and specificity, particularly in resource-limited, tuberculosis-endemic settings. Routine incorporation of DWI and MRS can reduce diagnostic ambiguity, guide targeted treatment, and improve clinical outcomes in patients with complex brain lesions.

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