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ORIGINAL RESEARCH ARTICLE

Evaluation of Brain Infection on Magnetic Resonance Imaging & Its Correlation with CSF Findings

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ABSTRACT

Introduction: Brain infections represent a complex diagnostic challenge in clinical neurology, requiring sophisticated diagnostic approaches. This study aimed to evaluate the correlation between magnetic resonance imaging (MRI) findings and cerebrospinal fluid (CSF) parameters in diagnosing brain infections.

Material and Methods: A prospective observational study was conducted on 64 patients suspected of brain infections. Participants underwent comprehensive MRI examinations using Siemens Magnetom Skyra 3 Tesla and Sempra 1.5 Tesla machines, along with detailed CSF analysis. Multiple diagnostic parameters were evaluated, including clinical presentation, imaging characteristics, and laboratory findings.

Results: The study population was predominantly male (54.7%), with most patients aged 20 to 40 years. Tubercular meningitis emerged as the most common diagnosis across diagnostic methods. MRI demonstrated high diagnostic accuracy, with 97.8% sensitivity for tubercular meningitis and 90.9% for viral infections. Clinical presentations were predominantly characterized by fever (84.4%) and headache (68.8%). Imaging revealed single lesions in 50% of patients, with the temporal region and basal ganglia as the most frequent infection sites. Significant variations in CSF parameters were observed across different infection types.

Conclusion: The study highlights the complementary nature of MRI and CSF analysis in diagnosing brain infections. The multi-modal approach proved crucial in accurately characterizing different types of neurological infections, emphasizing the importance of comprehensive clinical, imaging, and laboratory assessments.

Keywords: Magnetic resonance imaging, Meningitis, Cerebrospinal fluid analysis, Tubercular meningitis, Viral infections, Neurological infections, Imaging characteristics, Laboratory findings, Fever, Temporal region, Basal ganglia.

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INTRODUCTION

Brain infections present significant challenges in clinical neurology, requiring precise assessment strategies. The central nervous system (CNS) is vulnerable to bacterial, viral, fungal, and parasitic pathogens, each with unique diagnostic complexities. Magnetic resonance imaging (MRI) has become critical in evaluating neurological infections, providing high-resolution visualization of cerebral alterations. The relationship between neuroimaging findings and cerebrospinal fluid (CSF) analysis offers a comprehensive approach to understanding brain infections. Advanced neuroimaging techniques have expanded evaluation beyond conventional assessments, allowing detailed analysis of inflammatory processes and tissue changes.[1]

Despite advances, diagnosing CNS infections remains challenging, especially with atypical presentations. Key factors include:

Diverse Pathogens

Require sophisticated diagnostic techniques; limitations of current methods: Often lack comprehensive insights;

Need for accurate diagnosis - essential for targeted treatment. CSF analysis is vital, providing markers that complement MRI findings. Combining advanced MRI with CSF analysis can improve diagnostic accuracy and address uncertainties.[2-4]

Imaging Modalities

Computed tomography - wide availability and ability to quickly detect complications like hydrocephalus, mass effect/herniation, and bleeding;[5] magnetic resonance imaging - higher sensitivity for detecting leptomeningitis, empyema, ventriculitis, and complications like cerebral infarction.
Key MR sequences include:

Diffusion-weighted imaging (DWI)

Distinguishing pyogenic abscesses shows reduced diffusion (“light bulb bright”)

Fluid attenuated inversion recovery (FLAIR)

Sensitive for identifying leptomeningeal disease through hyperintensity in the subarachnoid space

T2-weighted (T2W)

Vasogenic edema and core signal intensity

T1-weighted post-gadolinium (GAD)

Evaluating enhancement patterns.

Magnetic resonance spectroscopy (MRS)

Characteristic metabolite patterns.
CT is used first due to speed and availability, but is less sensitive.

MRI is preferred for detailed assessment, with specific sequences (DWI, FLAIR, T2W, T1W-GAD, MRS) aiding in diagnosis and complication detection.

The main aim and objective of my study was to evaluate the correlation between MRI findings and cerebrospinal fluid parameters in patients with brain infections.

MATERIAL AND METHODS

This hospital-based prospective observational study was conducted over a period of 1.5 years in the Department of Radiodiagnosis at SRMSIMS Hospital, Bareilly, UP.

Sample Selection

Patients of all age groups, irrespective of sex, clinically suspected of brain infection, undergoing neuroimaging (MRI) and CSF analysis were included.

Patients not giving consent, having brain infection 'mimics' e.g. tumor, inflammation, head injury, hypoxic injury or suspected substance abuse, metallic implants and non-MR compatible devices, claustrophobia or having gadolinium contrast allergy were excluded.

Sampling, Including Sample Size Calculation

Study tool

Predesigned proforma for data collection, Informed consent form MRI machines:
- Siemens Magnetom Skyra 3 Tesla 48-Channel MRI Machine
- Siemens Magnetom Sempra 1.5 Tesla 16-Channel MRI Machine

Ethical Considerations

Ethical approval was obtained from the appropriate ethics committee before proceeding with the research.

Data Collection Procedure

This cross-sectional observational study in the Radiology and Neurology Department examined the correlation between MRI findings and CSF analysis in patients with suspected brain infections, using two MRI systems and central lab resources. Participants meeting inclusion criteria provided written informed consent, with age and sex recorded *via* a structured proforma

Data Collection Methodology

A predesigned proforma was developed for comprehensive data collection, incorporating the following key components:
- Demographic information
- Detailed medical history
- Clinical examination findings
- Biochemical investigation results
- Neuroimaging characteristics
- CSF analysis parameters

Cerebrospinal Fluid Analysis

Lumbar puncture was performed following standard clinical protocols:
- CSF collection under sterile conditions
- Comprehensive laboratory analysis including:
- Cell count and differential
- Protein and glucose levels
- Microbiological cultures
- Molecular diagnostic tests
- Inflammatory markers

Certainly! Here's a concise version of the statistical analysis section:

Statistical Analysis

Data were entered into Excel and analyzed with SPSS v21. Quantitative data were summarized using mean, median, standard deviation, and ranges. Qualitative data were expressed as frequencies and percentages. The Student's t-test (two-tailed) assessed mean differences, with $p < 0.05$ indicating significance.

RESULTS

Figure 1 depicts the age-wise distribution of study participants. The patients were distributed across different age groups, indicating that central nervous system (CNS) infections affect individuals of various ages. The majority of cases were observed in the younger and middle-aged population, reflecting the greater susceptibility of these age groups to infectious diseases of the brain and meninges.

Figure 2 shows the gender distribution of the study population. Males constituted a higher proportion of patients compared to females, suggesting a male predominance among patients presenting with brain infections in the present study.

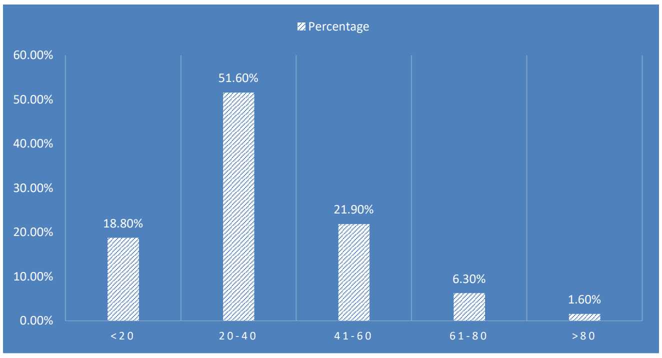


Figure 1: Distribution of patients according to age

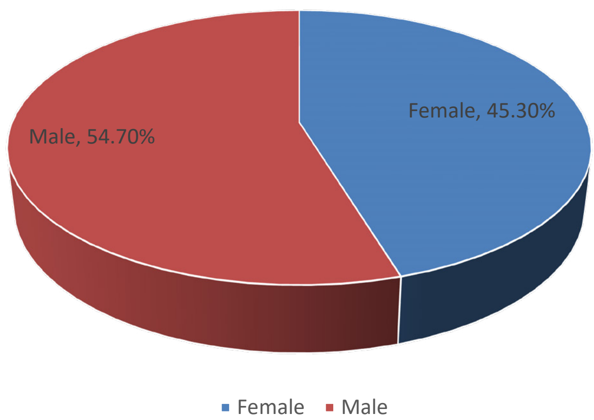


Figure 2: Distribution of patients according to gender

Table 1 summarizes the clinical manifestations of patients included in the study. Fever was the most common presenting symptom, observed in 54 (84.4%) patients, followed by headache in 44 (68.8%) patients and vomiting in 24 (37.5%) patients. Altered sensorium was present in 9 (14.1%) patients, while seizures, irrelevant talk, and weakness were noted in 4 (6.3%) patients each. These findings indicate that fever and headache were the predominant symptoms among patients with CNS infections.

Table 2 presents the mean values of various cerebrospinal fluid parameters. The mean total leukocyte count (TLC) was 136.6 ± 253.5 cells/mm^3. The mean polymorph and lymphocyte percentages were 31.4 ± 26.3 and 66.27 ± 27.5%, respectively. The mean CSF sugar level was 46.14 ± 31.2 mg/dL, while the mean protein level was markedly elevated at 248.2 ± 150.8 mg/dL. These findings suggest significant inflammatory changes within the CSF.

Table 3 shows the categorization of CSF parameters as normal or abnormal. Abnormal TLC was observed in 62 (96.8%) patients, while abnormal differential leukocyte count was present in 33 (51.5%) patients. CSF sugar levels were decreased in 35 (54.7%) patients, increased in 13 (20.3%), and normal in 16 (25%) patients. Elevated CSF protein levels were observed in 62 (96.8%) patients, indicating that abnormal CSF findings were present in the majority of cases.

Table 4 demonstrates the presence of perilesional oedema on MRI. Perilesional oedema was observed in 14 (21.9%) patients, whereas it was absent in 50 (78.1%) patients. Thus, the majority of patients did not demonstrate significant perilesional oedema on imaging.

Table 5 illustrates lesion signal characteristics on different MRI sequences. On T1-weighted images, lesions were predominantly hypointense in 62 (96.8%) patients, while only 2 (3.1%) lesions appeared isointense. On T2-weighted and FLAIR sequences, lesions were predominantly hyperintense in 62 (96.9%) patients. These signal characteristics are typical of infective and inflammatory brain lesions.

Table 6 presents the MRI-based diagnoses among study participants. Tubercular meningitis was the most common diagnosis, observed in 33 (53.1%) patients, followed by tuberculomas in 13 (20.3%) patients. Viral meningitis was diagnosed in 9 (14.0%) patients, fungal meningitis in 5 (7.8%), bacterial meningitis in 2 (3.1%), and viral meningoencephalitis and calvarial osteomyelitis in 1 (1.5%) patient each. Tuberculosis-related CNS infections constituted the majority of MRI diagnoses.

Table 7 shows the final etiological diagnosis based on CSF analysis. Tubercular meningitis was diagnosed in 47 (73.4%) patients, making it the most common infection. Viral infections accounted for 11 (17.1%) cases, while bacterial and fungal infections each accounted for 3 (4.6%) cases. The findings indicate a predominance of tuberculous infection in the study population. Table 8 presents the clinical diagnoses of the study participants. Tubercular meningitis was the most common clinical diagnosis, accounting for 35 (54.7%) cases, followed by viral encephalitis in 10 (15.6%) patients and TB meningitis with complications in 8 (12.5%) patients. Other diagnoses included fungal infections, pyogenic meningitis, meningoencephalitis, and miscellaneous conditions.

Table 9 evaluates the association between MRI diagnosis and CSF parameters using one-way ANOVA. Significant differences were observed among diagnostic groups with respect to polymorph count (p = 0.003), lymphocyte count (p <0.001), CSF sugar level (p <0.001), and CSF protein level (p = 0.001). However, no statistically significant difference was observed for TLC (p = 0.59). These findings suggest a significant correlation between MRI-based diagnosis and specific CSF biochemical and cytological parameters.

Table 10 compares MRI-based diagnoses with CSF-based diagnoses. Tubercular meningitis was diagnosed in 46 (71.8%) patients by MRI and 47 (73.4%) patients by CSF examination. Similarly, comparable frequencies were observed for viral encephalitis, bacterial meningitis, and

Table 1: Distribution of patients according to clinical presentation

Clinical presentation	*Frequency*	*Percentage*
Headache	44	68.8
Vomiting	24	37.5
Seizures	4	6.3
Fever	54	84.4
Altered sensorium	9	14.1
Irrelevant talk	4	6.3
Weakness	4	6.3

Table 2: Distribution of patients according to CSF findings

CSF findings	*TLC*	*Polymorphs*	*Lymphocytes*	*Sugar*	*Protein*
Mean	136.6	31.4	66.27	46.14	248.2
SD	253.5	26.3	27.5	31.2	150.8

Table 3: Distribution of patients according to CSF parameters

CSF	*Parameters*	*Frequency*	*Percentage*
TLC	Normal	2	3.1
	Abnormal	62	96.8
DLC (Polymorphs, lymphocytes)	Normal	31	48.5
	Abnormal	33	51.5
Sugar	Normal	16	25
	Increased	13	20.3
	Decreased	35	54.7
Protein	Normal	2	3.1
	Increased	62	96.8

Table 4: Distribution of patients according to perilesional oedema

Perilesional oedema	*Frequency*	*Percentage*
Present	14	21.9
Absent	50	78.1
Total	64	100

Table 5: Distribution of patients according to signal intensity

Signal intensity	*T1*	*T2*	*FLAIR*
Hyperintense	-	62 (96.9%)	62 (96.9%)
Hypointense	62 (96.8%)	1 (1.6%)	1 (1.6%)
Isotense	2 (3.1%)	1 (1.6%)	1 (1.6%)

Table 6: Distribution of patients according to MRI diagnosis

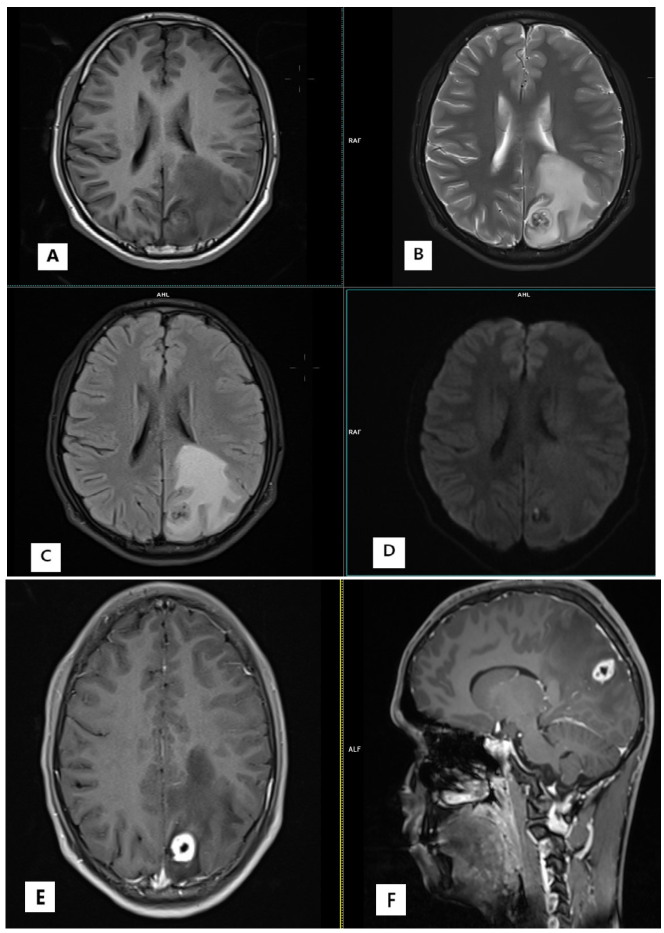
MRI diagnosis	*Frequency*	*Percentage*
Tubercular meningitis	33	53.1
Viral meningitis	9	14.0
Viral meningoencephalitis	1	1.5
Tuberculomas	13	20.3
Fungal meningitis	5	7.8
Calvarial osteomyelitis	1	1.5
Bacterial meningitis	2	3.1

Table 7: Distribution of patients according to CSF findings

CSF findings	*Frequency*	*Percentage*
Tubercular meningitis	47	73.4
Bacterial meningitis	3	4.6
Fungal	3	4.6
Viral infection	11	17.1

Table 8: Distribution of patients according to clinical diagnosis

Clinical diagnosis	*Frequency*	*Percentage*
Tubercular meningitis	35	54.7
Fungal	2	3.1
Meningitis	1	1.6
Meningoencephalitis	1	1.6
Pyogenic	2	3.1
TBM with complications	8	12.5
Viral encephalitis	10	15.6
Others	5	7.8



Case 1: A conglomerated ring enhancing lesion noted in left parieto-occipital region at cortical subcortical location. The lesion is appearing iso to hyperintense on T1Wis (A) and heterogeneously iso to hypointense on long TR images (B and C) with patchy areas of restricted diffusion (D) within them. There is mild surrounding perilesional edema, appearing hyperintense on long TR images (B and C) without any significant midline shift or ventricular compression. On post contrast images (E and F) there is peripheral and heterogeneous enhancement within it.

Table 9: Association of MRI with CSF findings

CSF parameters (mean ± SD)	*MRI diagnosis*				*p-value**
	Tubercular meningitis	*Viral encephalitis*	*Bacterial*	*Fungal*	
TLC	160.2 ± 283.7	82.5 ± 102.1	7.5 ± 3.5	28.3 ± 25.2	0.59
polymorphs	38.6 ± 26.1	9.5 ± 9.6	15 ± 21.2	10 ± 10	0.003
Lymphocytes	60.2 ± 26.02	90.5 ± 9.6	85 ± 21.2	90 ± 10	<0.001
Sugar	38.6 ± 26.2	81.5 ± 28.1	77 ± 29.7	42 ± 28	<0.001
Protein	291.6 ± 142.3	142.3 ± 102.1	88.5 ± 4.9	110.7 ± 88.6	0.001

*One-way ANOVA test

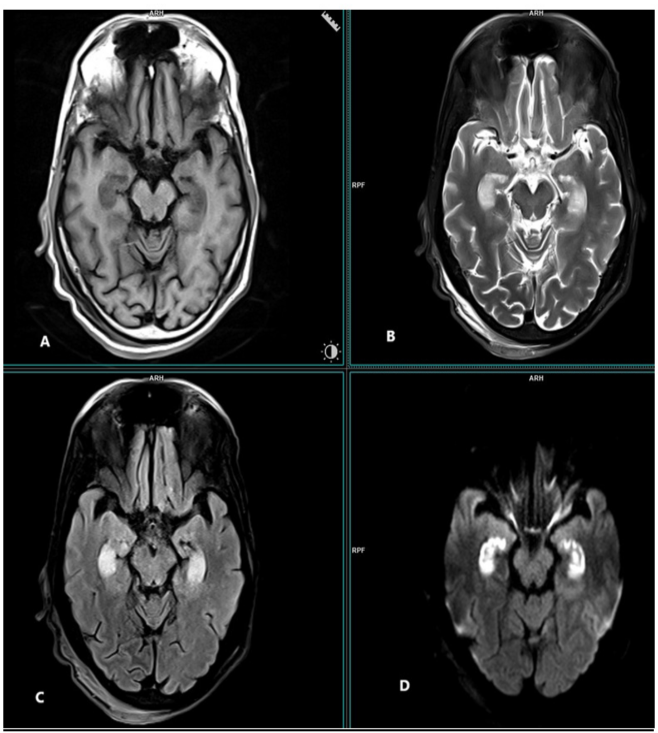
Table 10: Final diagnosis distribution

Diagnosis	*MRI-based*	*CSF-based*	*p-value**
Tubercular meningitis	46 (71.8%)	47 (73.4%)	0.843
Viral encephalitis	10 (15.6%)	11 (17.1%)	0.811
Bacterial meningitis	2 (3.1%)	3 (4.6%)	0.648
Fungal meningitis	5 (7.8%)	3 (4.6%)	0.465
Chronic calvarial oteomyelitis	1 (1.5%)	-	0.315

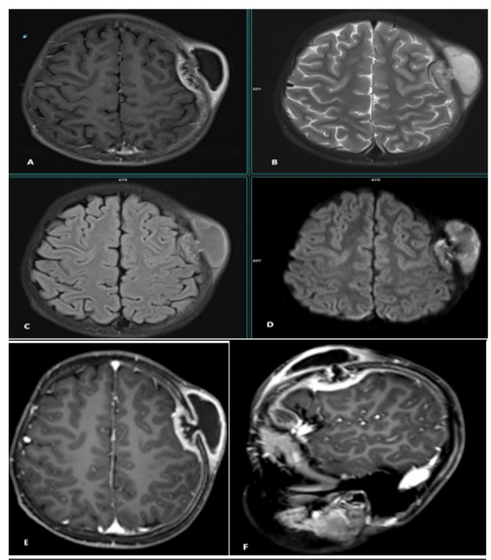
*Chi-square test

Table 11: Diagnostic accuracy of MRI in comparison with CSF

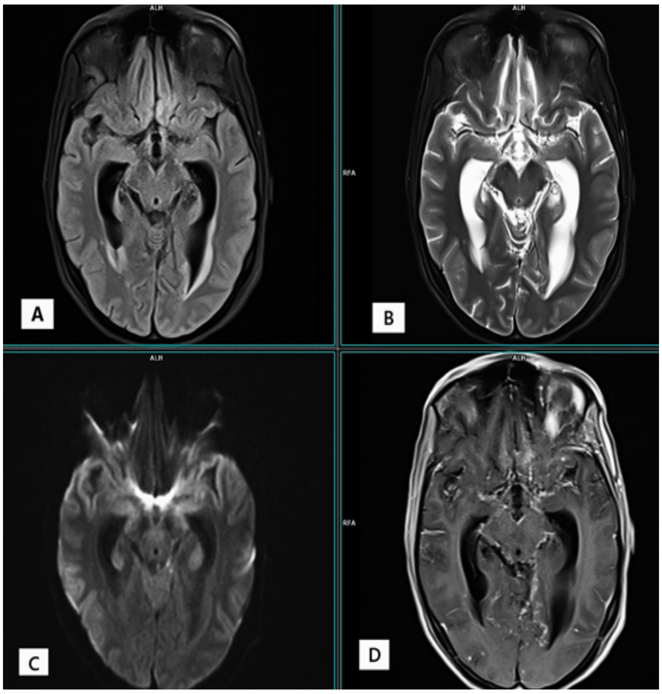
MRI	*Tubercular meningitis (%)*	*Viral (%)*	*Bacterial (%)*	*Fungal (%)*
Sensitivity	97.8	90.9	66.7	100
Specificity	94.1	100	98.4	96.7
PPV	97.8	100	100	60
NPV	94.1	98.1	96.8	100



Case 2: Symmetrical T1 (A) hypointensity T2 (B, and FLAIR (C) hyperintensities noted involving the B/L hippocampi (head, body and tail regions) with diffusion restriction on DWI (D) in B/L parietal periventricular white matter, basal ganglia and thalami (left > right). Prominence of ventricle and extra ventricle CSF spaces in the supratentorial compartment.



Case 3: Well-defined T1 hypointense (A), T2 hyperintense (B) with heterogeneous contents which is not suppressing on FLAIR (C) is noted epicentered over left frontoparietal calvaria having intracranial extra axial component as well as extracranial component causing elevation of overlying soft tissue. The lesion shows peripheral diffusion restriction on DWI (D). On post contrast study (E, F and G) shows thick heterogeneous predominantly peripheral enhancement with intralesional enhancing septations. Extra axial component of lesion is causing buckling of underlying grey white matter. Mild reactive enhancing dural thickening is also noted along left fronto-parietal convexity. Underlying bone shows defect through which extra axial and extracranial component of collection is communicating.



Case 4: T1 post contrast sequences (D) show prominent leptomeningeal enhancements noted along bilateral cerebral convexity as well as folia-based location with tiny cortical and subcortical foci of nodular enhancement. Basal exudates are noted around peri mesencephalic and prepontine cisterns suggestive of tubercular meningitis.
Communicating hydrocephalus noted, without any obvious transition or abrupt cut off. Maximum transverse caliber of third ventricle measures 11 mm and temporal horn measures 12 mm. Mild periventricular ooze noted around bilateral lateral ventricles.

fungal meningitis. No statistically significant differences were found between MRI and CSF diagnoses ($p > 0.05$), indicating good agreement between the two modalities.

Table 11 shows the diagnostic performance of MRI using CSF findings as the reference standard. MRI demonstrated high sensitivity and specificity for tubercular meningitis (97.8 and 94.1%, respectively) and viral infections (90.9 and 100%, respectively). For fungal infections, MRI showed 100% sensitivity and 96.7% specificity. Although the sensitivity for bacterial meningitis was relatively lower (66.7%), specificity remained high (98.4%). Overall, MRI exhibited excellent diagnostic accuracy in the evaluation of CNS infections.

DISCUSSION

In this cross-sectional observational study, the majority of patients (51.6%) with suspected brain infections were aged 20 to 40 years, followed by 21.9% aged 41 to 60 years, aligning with Kumar *et al.*'s findings of CNS infections predominantly affecting young adults. A slight male predominance (54.7%) was observed, consistent with Vanjare *et al.*'s reported male-to-female ratio of 1.3:1. The most common symptoms were fever (84.4%) and headache (68.8%), followed by vomiting (37.5%), corroborating Thwaites *et al.*'s findings in tuberculous meningitis. Seizures were less frequent (6.3%) compared to Misra *et al.*'s 15 to 20%, possibly due to differences in infection types and presentation timing. Data were collected using a structured proforma, and the study, conducted in the Radiology and Neurology Department with ethical approval, utilized two MRI systems and CSF analysis to explore correlations in neuroimaging and biochemical findings.

CSF Parameters and Their Diagnostic Significance

In this cross-sectional study in the Radiology and Neurology Department, CSF analysis of patients with suspected brain infections showed abnormal findings in 96.8%, with elevated TLC and mean CSF protein of 248.2 mg/dL (SD: 150.8), consistent with Marais *et al.*'s tuberculous meningitis findings. Lymphocytic predominance (mean: 66.27%, SD: 27.5) aligned with Tunkel *et al.*'s guidelines for tuberculous and viral meningitis. CSF glucose was reduced in 54.7% of cases (mean: 46.14 mg/dL, SD: 31.2), supporting Chin *et al.*'s review, particularly for tuberculous meningitis, which dominated the cohort. Data were collected *via* a structured proforma, with ethical approval, using two MRI systems to correlate with CSF findings.

MRI Findings and their Correlation with Different Types of Infections

Pattern and distribution of lesions

In our study, 50% of patients with suspected brain infections had single lesions, and 46.9% had multiple lesions, with the temporal region and basal ganglia most commonly affected (15.6% each), followed by white matter (10.9%), aligning with Gupta *et al.*'s findings of 21% basal ganglia involvement in CNS tuberculosis. MRI signal characteristics showed 96.8% of lesions as hypointense on T1 and 96.9% as hyperintense on T2 and FLAIR sequences, consistent with Kamra *et al.*'s findings in neuro-tuberculosis. Data were collected using a structured proforma, with ethical approval, and two MRI systems were used to correlate neuroimaging with CSF analysis findings.

Enhancement Patterns and Additional MRI Features

In this cross-sectional study in the Radiology and Neurology Department, 82.8% of patients with suspected brain infections showed meningeal enhancement on MRI, aligning with Wasay *et al.*'s 75 to 90% in tuberculous meningitis. SWI blooming was observed in 87.5% of cases, higher than Zhang *et al.*'s 65%. Restricted diffusion occurred in 60.9% of cases, consistent with Vaswani *et al.*'s 55 to 70% in acute CNS infections, aiding in differentiating infection types and assessing disease activity. Data were collected *via* a structured proforma, with ethical approval, using two MRI systems to correlate with CSF analysis.

Diagnostic Accuracy and Correlation with Clinical Diagnosis

In this cross-sectional study in the Radiology and Neurology Department, MRI showed high sensitivity (97.8%) and specificity (94.1%) for tuberculous meningitis, outperforming Patel *et al.*'s 86% and 90%, with a 97.8% positive predictive value. For viral infections, MRI had 90.9% sensitivity and 100% specificity, surpassing Singh *et al.*'s 85 and 95%. Bacterial meningitis showed moderate sensitivity (66.7%) but high specificity (98.4%), aligning with Cohen *et al.*, while fungal infections had perfect sensitivity (100%) but a lower positive predictive value (60%), per Kumar *et al*. Concordance between MRI (71.8%), CSF (73.4%), and clinical diagnosis (67.1%) for tuberculous meningitis, similar to Raut *et al.*'s findings, underscores the value of a multi-modal diagnostic approach. Data were collected *via* a structured proforma, with ethical approval, using two MRI systems.

CONCLUSION

This study confirms tubercular meningitis as the predominant brain infection diagnosed across multiple modalities. The synergistic use of MRI and CSF analysis was critical for accurate diagnosis, each providing unique insights. MRI exhibited high diagnostic precision, with 97.8% sensitivity and 94.1% specificity for tubercular meningitis, and 90.9% sensitivity with 100% specificity for viral infections, though bacterial and fungal infections showed variable performance. Clinically, fever (84.4%) and headache (68.8%) were the most common symptoms. CSF analysis revealed significant differences in polymorphs, lymphocytes, sugar, and protein levels across infection types, supporting differential diagnosis. These findings highlight the necessity of integrating clinical evaluation, advanced MRI, and detailed CSF analysis to achieve precise diagnosis and improve outcomes in neurological infections.

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