ORIGINAL ARTICLE

# Diagnostic accuracy of MRI contrast enhanced FLAIR and T1-weighted images in diagnosis of infectious meningitis taking CSF analysis as reference standard

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## ABSTRACT

**Background:** Early diagnosis of infectious meningitis is critical to reduce morbidity and mortality, particularly in paediatric patients where delayed diagnosis may lead to severe neurological complications. The objective of this study is to determine the diagnostic accuracy of contrast-enhanced FLAIR MRI and post-contrast T1-weighted MRI for the diagnosis of infectious meningitis in children, using cerebrospinal fluid analysis as the reference standard.

**Material and Methods:** This Cross-sectional study was conducted at Department of Diagnostic Radiology, Sir Ganga Ram Hospital, Lahore, from 3rd January 2026 to 10th April 2026. A total of 154 children aged ≤15 years with clinical suspicion of infectious meningitis were enrolled through non-probability consecutive sampling. All participants underwent contrast-enhanced FLAIR and post-contrast T1-weighted brain MRI. CSF analysis, including cytological, biochemical, and microbiological assessment, was used as the reference standard as CSF findings consistent or not consistent with infectious meningitis.

**Results:** The mean age was 8.17 ± 4.4 years, and 90 (58.4%) participants were male. CSF findings were consistent with infectious meningitis in 104 (67.5%) cases. Contrast-enhanced FLAIR MRI showed leptomeningeal enhancement suggestive of infectious meningitis in 100 (64.9%) patients, whereas post-contrast T1-weighted MRI was positive in 93 (60.4%) patients. CE-FLAIR showed a sensitivity, specificity, PPV, NPV, and overall accuracy of 92.3%, 92.0%, 96.0%, 85.2%, and 92.2%, respectively. Corresponding values for post-contrast T1-weighted MRI were 81.7%, 84.0%, 91.4%, 68.9%, and 82.5%, respectively.

**Conclusion:** ~~C~~Contrast-enhanced FLAIR MRI showed higher sensitivity, specificity, predictive values, and overall diagnostic accuracy than post-contrast T1-weighted MRI for detecting infectious meningitis.

**Keywords:** Cerebrospinal fluid, Child, Magnetic resonance imaging, Meningitis, Sensitivity and specificity

## BACKGROUND

The inflammation of the protective layers that cover the brain and spinal cord is known as meningitis[1]. These membranes are composed of three layers in which the outer is the dura mater, the middle is the arachnoid mater, and the inner is the pia mater. The leptomeninges are the arachnoid and pia mater that surround the subarachnoid space that houses the cerebrospinal fluid (CSF)[1,2]. Meningitis is a significant health issue all over the world, which annually causes about 422,900 deaths and leaves about 2,628,000 persons with permanent disabilities. It may be caused by various types of infectious agents, such as bacteria, viruses, fungi, and parasites, and patterns may vary in regions and age groups[3]. The prevalence in our part is estimated at approximately 15%[2]. High rates of morbidity and mortality result from a missed diagnosis or identification[4]. Patients admitted to a hospital with tuberculous meningitis have a mortality rate of almost 42 percent. When it comes to acute bacterial meningitis, timely treatment is very crucial, because delays in the process of giving antibiotics can result in death. A, 4 to 6 hours delay in the start of antibiotics has been found to risk the deaths by about 8.4 times especially among children and the elderly[4,5]. Laboratory diagnosis in meningitis is based on examination of cerebrospinal fluid[6]. Fluid-attenuated inversion recovery (FLAIR) is an MR imaging sequence with long repetition time (TR), echo time (TE), and inversion time (TI), which effectively suppresses cerebrospinal fluid signals, thereby increasing the detection of pathological alterations[5]. Because there is very little to no vascular enhancement in post-contrast FLAIR images, it has taken the lead over post-contrast T1-weighted imaging in the visualization of infectious leptomeningeal

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disease[5]. Jawwad *et al* in a Pakistan reported diagnostic accuracy of contrast enhanced FLAIR MRI in early diagnosis of infectious meningitis. Sensitivity and specificity of FLAIR MRI were 91.0% and 85.0% while sensitivity and specificity of MRI T1W were 60.2% and 77.5% respectively[8]. A study conducted in India reported that contrast-enhanced FLAIR MRI had significantly higher diagnostic accuracy than post-contrast T1-weighted imaging for the early diagnosis of infectious meningitis (94.73% vs. 70.17%; $p<0.05$), using CSF analysis as the reference standard. The sensitivity and specificity of contrast-enhanced FLAIR MRI were 96.0% and 85.71%, respectively, compared with 68.0% and 85.71% for post-contrast T1-weighted imaging, the prevalence of infectious meningitis was 68 %[9]. However, the preceding evidence is limited to just two studies that used CSF analysis as the gold standard to compare contrast enhanced FLAIR MRI with post contrast T1 images. The purpose of this study was to add to the existing literature by evaluating the diagnostic performance of contrast-enhanced FLAIR MRI and post-contrast T1-weighted MRI in patients with clinically suspected infectious meningitis. The study aimed to evaluate diagnostic performance of CE-FLAIR MRI and post-contrast T1-weighted imaging for early detection of infectious meningitis using CSF analysis as the reference standard.

## MATERIAL AND METHODS

This cross-sectional study was conducted at Department of Diagnostic Radiology, Sir Ganga Ram Hospital, Lahore from 3rd January 2026 to 10th April 2026. A sample size of 154 participants was calculated to estimate the diagnostic performance of contrast-enhanced FLAIR MRI with 95% confidence and 10% absolute precision, considering an anticipated sensitivity of 91%, specificity of 85%[8] and an expected infectious meningitis prevalence of 68%[9]. A non-probability consecutive sampling technique was used to enroll patients fulfilling the inclusion criteria. Patients of either gender, one month to 15 years, who presented with clinical features suggestive of meningitis and underwent both contrast-enhanced brain MRI and lumbar puncture for CSF analysis were included. The final classification of meningitis was based on the predefined CSF reference-standard criteria. Clinical suspicion was based on symptoms such as fever, neck stiffness, altered consciousness, headache, vomiting, seizures, irritability, or positive meningeal signs. Patients with incomplete MRI or CSF records, those medically unfit for lumbar puncture, and those with known neurological disorders or systemic conditions that could mimic meningitis were excluded. After obtaining ethical approval from the institutional review committee (ERC No: 03-synopsis/MD Radiology-I/FJ/ERC, Dated:01-01-2026), 154 patients meeting the inclusion criteria were enrolled in the study. Written informed consent was obtained from the attendants of each patient. A detailed clinical history and relevant demographic data were recorded on a structured proforma.

MRI of the brain was performed using a 1.5 Tesla scanner, covering the region from the vertex to the base of the skull. Both contrast-enhanced T1-weighted and contrast-enhanced FLAIR sequences were acquired. T1-weighted imaging was performed with TR 500 ms, TE 7.8 ms, FOV 230 mm, matrix 224 × 256, slice thickness 5 mm with a 1.5 mm interslice gap, right-to-left phase encoding, and an acquisition time of approximately 3 minutes 48 seconds. FLAIR imaging was obtained with TR 9000 ms, TE 109 ms, TI 2500 ms, and similar spatial parameters, with an acquisition time of approximately 2 minutes 8 seconds. All patients received intravenous gadolinium contrast medium, administered according to body weight using a computer-controlled injector at a rate of 0.2 mL/second. Contrast-enhanced FLAIR and post-contrast T1-weighted images were assessed separately for each participant by a single consultant radiologist with at least 8 years of experience. For each sequence, leptomeningeal enhancement was recorded as present or absent. A CE-FLAIR examination was considered positive when leptomeningeal enhancement was observed on contrast-enhanced FLAIR images, while post-contrast T1-weighted MRI was considered positive when enhancement was observed on post-contrast T1-weighted images. Enhancement detected on both sequences was recorded as positive for both index tests. The final classification of infectious meningitis was based on the CSF reference standard. CSF samples were obtained and analyzed in the laboratory by a qualified pathologist who was blinded to MRI findings. CSF analysis included physical examination, cytology and biochemical parameters (glucose and protein levels). All MRI examinations were performed on the same machine, and CSF analyses were conducted by the same pathologist to minimize inter-observer variability.

Confounding variables were controlled through strict exclusion criteria. All relevant data, including demographic details, MRI findings, and CSF results, were recorded on a structured proforma.

Data were entered and analyzed using Statistical Package for the Social Sciences (SPSS) version 25.0. Quantitative variables such as age, CSF protein, glucose and leucocyte count were presented as mean ± standard deviation. Normality of quantitative variables was assessed using the Shapiro–Wilk test. Normally distributed variables were presented as mean ± standard deviation. Qualitative variables, including gender, presence of meningitis on contrast-enhanced FLAIR MRI, post-contrast T1 MRI, and CSF analysis, were expressed as frequencies and percentages. Diagnostic accuracy parameters, including sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV), were calculated for both contrast-enhanced FLAIR MRI and post-contrast T1 MRI, using CSF analysis as the reference standard. A p-value of ≤0.05 was considered statistically significant.

## RESULTS

Mean age of children was 8.17 ± 4.4 years. There was a male predominance, with 90 (58.4%) males and 64 (41.6%) females. All patients presented with fever and neck stiffness 132 (85.7%), while altered consciousness was observed in 71 (46.1%) patients. CSF analysis showed a mean protein level of 165.69 ± 49.07 mg/dL, mean glucose level of 40.89 ± 11.4 mg/dL, and mean cell count of 431.18 ± 211.4 cells/mm³ (Table-I).

Out of 104 CSF-positive cases, CE FLAIR MRI correctly identified 96 true positives (92.3%), while 8 cases (7.7%) were false negatives. Among 50 CSF-negative cases, 46 were true negatives (92.0%) and 4 were false positives (8.0%). Overall, CE FLAIR MRI correctly classified 142 out of 154 cases (92.2%) (Table-II). Post-contrast T1 MRI detected 85 true positives (81.7%) among 104 CSF-positive cases, with 19 false negatives (18.3%). Among 50 CSF-negative cases, 42 were true negatives (84.0%) and 8 were false positives (16.0%). Overall, 127 out of 154 cases (82.5%) were correctly classified (Table-III).

**Table-I: Baseline Demographic, Clinical, and CSF Characteristics of Participants (n = 154)**

| Variable | n (%) / Mean ± SD |
|---|---|
| **Demographic characteristics** | |
| Age (years) | 8.17 ± 4.40 |
| Gender – Male | 90 (58.4) |
| Female | 64 (41.6) |
| **Clinical characteristics** | |
| Fever – Yes | 154 (100.0) |
| Neck stiffness – Yes | 132 (85.7) |
| Altered consciousness – Yes | 71 (46.1) |
| Headache – Yes | 89 (57.8) |
| Vomiting – Yes | 76 (49.4) |
| Seizures – Yes | 43 (27.9) |
| Kernig's sign – Yes | 68 (44.2) |
| Brudzinski's sign – Yes | 61 (39.6) |
| **CSF characteristics** | |
| CSF protein (mg/dL) | 165.69 ± 49.07 |
| CSF glucose (mg/dL) | 40.89 ± 11.40 |
| CSF cell count (cells/mm³) | 431.18 ± 211.40 |

**Table-II: Diagnostic Accuracy of CE FLAIR MRI Taking CSF as Gold Standard (N=154)**

| Diagnostic parameter | CE-FLAIR MRI, % / Ratio (95% CI) |
|---|---|
| Sensitivity | 92.3% (85.6–96.1) |
| Specificity | 92.0% (81.2–96.8) |
| Positive predictive value | 96.0% (90.2–98.4) |
| Negative predictive value | 85.2% (73.4–92.3) |
| Positive likelihood ratio | 11.54 (4.50–29.59) |
| Negative likelihood ratio | 0.08 (0.04–0.16) |
| Overall diagnostic accuracy | 92.2% (86.9–95.5) |

**Table-III: Diagnostic Performance of Post-Contrast T1-Weighted MRI Using CSF Analysis as the Reference Standard**

| Post-contrast T1-weighted MRI | CSF reference-standard positive |
|---|---|

| | |
|---|---|
| Sensitivity | 81.7% (73.2–88.0) |
| Specificity | 84.0% (71.5–91.7) |
| Positive predictive value | 91.4% (83.9–95.6) |
| Negative predictive value | 68.9% (56.4–79.1) |
| Positive likelihood ratio | 5.11 (2.69–9.70) |
| Negative likelihood ratio | 0.22 (0.14–0.33) |
| Overall accuracy | 82.5% (75.7–87.7) |

## DISCUSSION

This study evaluated the diagnostic accuracy of contrast-enhanced FLAIR MRI and post-contrast T1-weighted imaging in the early detection of infectious meningitis using CSF analysis as the reference standard. Contrast-enhanced FLAIR MRI outperformed conventional post-contrast T1 sequences in the early diagnosis of meningitis, as demonstrated by the findings. In the present study, the frequency of infectious meningitis confirmed by CSF analysis was 67.5%, reflecting a high burden of disease in the studied pediatric population. This is in line with previous data from tertiary care settings, where stringent inclusion criteria ensure that CSF analysis confirms a high proportion of clinically suspected cases. Early identification of these cases is critical to prevent complications and improve outcomes[10]. Quantitative comparisons of CE-FLAIR's sensitivity, specificity, and overall diagnostic performance should be made with studies that have already been published. When interpreting differences, the patient's age, the aetiology of the disease, the MRI protocol, the timing of the imaging, and prior antimicrobial exposure should all be taken into consideration. The clinical implications of the 19 false-negative post-contrast T1-weighted MRI examinations should also be discussed.When clinically suspected of having meningitis, a negative T1-weighted MRI may offer false comfort and delay the identification of meningeal inflammation or the appropriate treatment. As a result, a negative post-contrast T1-weighted sequence should be interpreted alongside clinical findings, CSF results, and CE-FLAIR imaging to rule out meningitis, particularly in early stages of the disease.

The diagnostic accuracy of contrast-enhanced FLAIR MRI was notably high, with sensitivity of 92.3% and specificity of 92.0%. These findings indicate that CE FLAIR MRI is highly effective in detecting meningeal inflammation, even in early stages of disease. The superior performance of this sequence can be attributed to its ability to suppress CSF signals, thereby enhancing the visibility of subtle leptomeningeal enhancement[11,12]. Similar findings have been reported in previous studies, where CE FLAIR demonstrated higher sensitivity compared to conventional sequences in detecting meningitis, particularly in cases with minimal or early inflammatory changes[13].

In comparison, post-contrast T1-weighted imaging showed lower sensitivity (81.7%) and specificity (84.0%) in this study. T1-weighted imaging is still the most common method for assessing meningeal enhancement, but its diagnostic accuracy may be limited in the early stages of disease due to the lack of contrast between inflamed meninges and CSF. The higher number of false-negative cases observed with T1 imaging further supports its comparatively lower sensitivity in early detection[14]. This highlights the clinical importance of incorporating contrast-enhanced FLAIR sequences into routine MRI protocols for suspected meningitis[15]. Early and accurate detection using CE FLAIR MRI can facilitate timely initiation of appropriate therapy, thereby reducing morbidity and mortality[16-18]. The strong agreement between CE FLAIR MRI and CSF analysis further reinforces its reliability as a diagnostic tool[19,20].

This study has several limitations. First, it was conducted at a single centre with a modest sample size, which may limit the generalisability of the findings. Second, both contrast-enhanced FLAIR and post-contrast T1-weighted images were interpreted by the same radiologist. This may have introduced intra-observer correlation between the two index-test readings and limited their independence. Observer bias and review bias are also possible, particularly if interpretation of one sequence influenced assessment of the other sequence. As no repeat blinded assessment or second independent radiologist was included, intra-observer and inter-observer agreement could not be evaluated. Third, the use of a single MRI scanner and imaging protocol may limit reproducibility across centres. Finally, the study did not report the complete etiological classification of infectious meningitis or culture-positivity data, which limits interpretation across bacterial, viral, tuberculous, and fungal meningitis.

## CONCLUSION

Contrast-enhanced FLAIR MRI demonstrated higher observed sensitivity, specificity, predictive values, and overall diagnostic accuracy than post-contrast T1-weighted MRI for detecting leptomeningeal enhancement, using CSF analysis as the reference standard. These findings suggest that CE-FLAIR may be a useful adjunct to post-contrast T1-weighted imaging in children with clinical suspicion of infectious meningitis. However, as formal paired statistical comparisons between the two MRI sequences were not available, definitive superiority of CE-FLAIR cannot be concluded. Further adequately powered studies using clearly defined microbiological or composite reference standards are needed.

## CONFLICT OF INTEREST

None

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Declared none

## AUTHOR CONTRIBUTION

**Ammara Akram:** Substantial contribution to study design and data acquisition, manuscript drafting and critical review, final approval of the version to be published.

**Saman Chaudhry:** Supervision of study design and methodology, critical manuscript review, final approval of the version to be published

**Sana Arbab:** Analysis and interpretation of data, critical manuscript review, final approval of the version to be published

**Noor ul Ain Lali:** Data acquisition and management, manuscript drafting and review, final approval of the version to be published

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