

Diagnostic Accuracy of Contrast-Enhanced T2-FLAIR MRI in diagnosing Infective Meningitis taking CSF analysis as gold standard

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Manuscript type	Study design	Sample	Ethics approval
Original research	Cross-sectional diagnostic-accuracy study	n = 142	IHHN_IRB_2026_03_002

Abstract

Objective: To determine the diagnostic accuracy of contrast-enhanced T2 fluid-attenuated inversion recovery (CE-T2-FLAIR) MRI in diagnosing infective meningitis, taking cerebrospinal fluid (CSF) analysis as gold standard.

Methods: In this cross-sectional diagnostic-accuracy study, 142 consecutive adults aged 18-65 years with clinically suspected meningitis underwent 1.5-T brain MRI and CSF analysis. CE-T2-FLAIR was positive when abnormal meningeal enhancement was visible in extra-axial CSF spaces, along superficial brain surfaces, within sulci, or along cranial nerves and cisterns. CSF positivity required pleocytosis of at least 50 cells/ μ L, protein of at least 40 mg/dL, and a CSF-to-blood glucose ratio of 0.40 or less. Sensitivity, specificity, predictive values, and accuracy were calculated with Wilson 95% confidence intervals.

Results: CSF confirmed infective meningitis in 86/142 participants (60.56%). CE-T2-FLAIR produced 82 true-positive, 10 false-positive, 4 false-negative, and 46 true-negative results. Sensitivity was 95.35% (88.64%-98.18%), specificity 82.14% (70.16%-90.00%), positive predictive value 89.13% (81.14%-93.99%), negative predictive value 92.00% (81.16%-96.85%), and overall accuracy 90.14% (84.13%-94.04%). Accuracy was similar across sex and prespecified age strata.

Conclusion: CE-T2-FLAIR demonstrated high sensitivity and overall diagnostic accuracy for detecting infective meningitis. It can serve as a useful adjunct for recognizing subtle meningeal inflammation and complications, but it should complement rather than replace timely CSF examination and microbiological testing.

Keywords: contrast-enhanced MRI; T2-FLAIR; infective meningitis; cerebrospinal fluid; diagnostic accuracy; meningeal enhancement.

Introduction

Meningitis is inflammation of the leptomeninges and subarachnoid space caused by bacterial, viral, tuberculous, fungal, or parasitic infection. It remains a medical emergency because delayed recognition and treatment can lead to death, neurological disability, seizures, hydrocephalus, infarction, and cognitive impairment. The World Health Organization recommends prompt lumbar puncture and CSF examination when acute meningitis is suspected, provided this does not delay antimicrobial therapy or expose a patient with contraindications to harm.¹

CSF analysis is the clinical reference standard, but neuroimaging has an important complementary role. It identifies contraindications to immediate lumbar puncture, detects complications, and may demonstrate meningeal inflammation when routine imaging is equivocal. MRI provides superior soft-tissue contrast and avoids posterior fossa bone artifact. Typical enhancement is thin and linear in many acute bacterial or viral infections, whereas basal, thick, or nodular enhancement may occur in tuberculosis, fungal disease, or neoplastic meningitis.²⁻⁵

Post-contrast T2-FLAIR suppresses free CSF signal and reduces conspicuity of enhancing vessels, allowing low concentrations of gadolinium in inflamed meninges or CSF to become visible against a dark background. Prior diagnostic studies have reported sensitivities above 90%, although specificity varies because oxygen supplementation, motion, vascular signal, prior procedures, and noninfectious leptomeningeal disease can produce FLAIR hyperintensity or enhancement.⁶⁻¹² A recent 2025 study also found that CE-T2-FLAIR had greater sensitivity and accuracy than conventional post-contrast T1-weighted imaging.¹³

Local validation is important because disease spectrum, MRI timing, technical parameters, reader experience, and reference-standard definitions affect measured performance. The present study therefore evaluated CE-T2-FLAIR in adults with suspected infective meningitis using predefined CSF biochemical and cellular criteria as the reference standard.

Objective: To determine the sensitivity, specificity, positive predictive value, negative predictive value, and overall accuracy of CE-T2-FLAIR MRI for infective meningitis, taking CSF analysis as the reference standard.

Materials and Methods

Study design and setting

This was a descriptive cross-sectional diagnostic-accuracy study conducted in the Department of Diagnostic Radiology, Recep Tayyip Erdogan Hospital, Muzaffargarh, Pakistan. The approved protocol specified six months of non-probability consecutive recruitment. The exact recruitment start and end dates were not stated in the supplied study documents and must be inserted before journal submission.

Participants

Adults aged 18-65 years of either sex were eligible when meningitis was clinically suspected on the basis of fever, headache, altered consciousness, fits, or photophobia together with neck rigidity and Kernig or

Brudzinski signs, and when contrast-enhanced MRI had been requested. Exclusion criteria were estimated glomerular filtration rate below 30 mL/min, recurrent disease, pacemaker, prosthetic valve, aneurysm clip, metallic plate or other ferromagnetic material, claustrophobia, or excessive irritability/motion precluding diagnostic imaging.

Sample size and sampling

A sample of 142 participants was calculated for one-sample sensitivity and specificity using an expected disease prevalence of 60.3%, sensitivity of 95.08%, specificity of 82.5%, 95% confidence level, and 10% absolute precision. Participants were enrolled consecutively.

Index test: CE-T2-FLAIR MRI

MRI was performed from vertex to skull base on a 1.5-T GE Healthcare Signa Voyager system. The protocol included T1- and T2-weighted turbo spin-echo images in axial, coronal, and sagittal planes, diffusion-weighted imaging, apparent diffusion coefficient maps, and axial T2-FLAIR. Gadolinium-based contrast was administered at 0.1 mmol/kg. Axial contrast-enhanced T1-weighted images were acquired after approximately 1 minute and CE-T2-FLAIR images after approximately 2.5 minutes. Consultant radiologists with 5-10 years of experience interpreted the examinations. CE-T2-FLAIR was classified as positive when meningeal enhancement was present in extra-axial CSF spaces, along superficial brain surfaces or sulci, or along cranial nerves and cisterns. The supplied records did not document whether readers were blinded to CSF results; this must be confirmed before submission.

Reference standard

All participants underwent lumbar puncture, and CSF was examined in a single laboratory for cell count, protein, and glucose. Infective meningitis was defined a priori as the simultaneous presence of CSF pleocytosis of at least 50 cells/ μ L, CSF protein of at least 40 mg/dL, and a CSF-to-blood glucose ratio of 0.40 or less. The elapsed time between MRI and lumbar puncture, antimicrobial exposure between tests, microbiological culture or molecular testing, and test-related adverse events were not available in the supplied dataset.

Statistical analysis

Participant characteristics were summarized using mean and standard deviation or median and range for continuous variables and frequency and percentage for categorical variables. CE-T2-FLAIR and CSF results were cross-tabulated to obtain true-positive, false-positive, false-negative, and true-negative counts. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), disease prevalence, and overall accuracy were calculated with two-sided Wilson 95% confidence intervals. Prespecified stratified analyses were performed by sex and age (18-40 and 41-65 years). There were no missing or indeterminate index-test or reference-standard results. Analyses were reproduced independently from the supplied patient-level spreadsheet.

Ethical considerations

The study protocol was approved by the Indus Hospital & Health Network Institutional Review Board (IHNN_IRB_2026_03_002; approval date 17 July 2026; expiry date 16 July 2027) under expedited review category 04. The approved protocol required informed consent and protection of participant confidentiality. The CPSP Research Evaluation Unit approved the article synopsis (CPSP/REU/RAD-2023-293-4060; 13 February 2025).

Results

Participant characteristics

All 142 records were complete and included in the analysis. Mean age was 42.81 ± 14.66 years; 74 participants (52.1%) were male and 68 (47.9%) female. Median symptom duration was 10 days (range 1-21). CSF confirmed infective meningitis in 86 participants (60.6%), while CE-T2-FLAIR was positive in 92 (64.8%).

Table 1. Baseline clinical and laboratory characteristics (n = 142)

Characteristic	Summary
Age, years	42.81 ± 14.66 ; median 43 (18-65)
Male sex	74 (52.1%)
Female sex	68 (47.9%)
Symptom duration, days	10.78 ± 6.13 ; median 10 (1-21)
Temperature, °C	38.96 ± 0.73
Altered consciousness	50 (35.2%)
Fits	28 (19.7%)
Photophobia	92 (64.8%)
Positive Kernig sign	104 (73.2%)
Positive Brudzinski sign	90 (63.4%)
CSF cell count, cells/ μ L	median 156.5 (1-970)
CSF protein, mg/dL	median 72.5 (19-244)
CSF:blood glucose ratio	0.393 ± 0.136
CSF-positive infective meningitis	86 (60.6%)

Values are n (%), mean $\pm$ standard deviation, or median (range), as indicated.

Diagnostic performance

Table 2. CE-T2-FLAIR MRI versus CSF reference standard

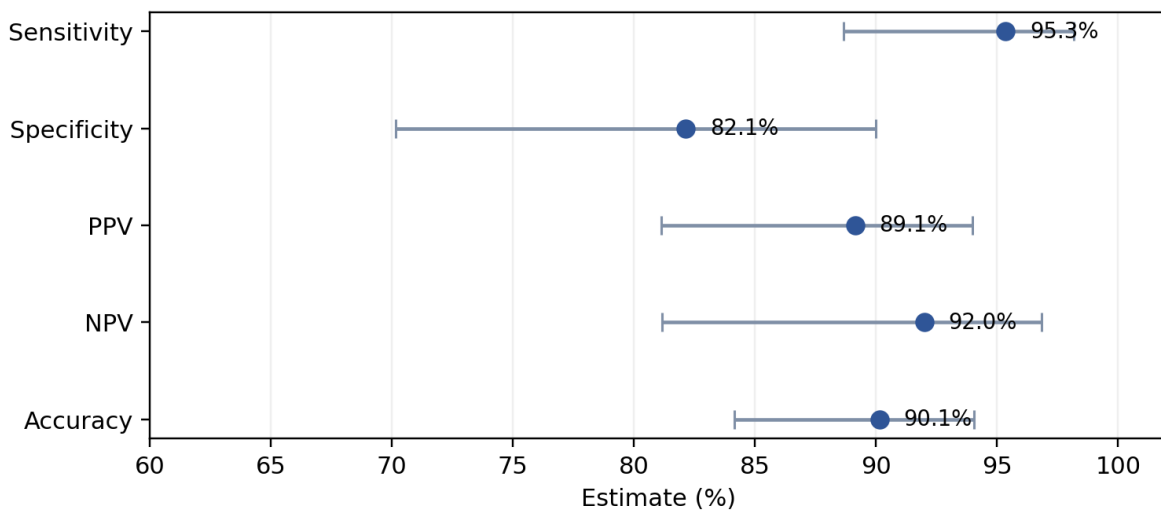
CE-T2-FLAIR	CSF positive	CSF negative	Total
Positive	82 (true positive)	10 (false positive)	92
Negative	4 (false negative)	46 (true negative)	50
Total	86	56	142

CE-T2-FLAIR achieved a sensitivity of 95.35% (88.64%-98.18%), specificity of 82.14% (70.16%-90.00%), PPV of 89.13% (81.14%-93.99%), NPV of 92.00% (81.16%-96.85%), and overall accuracy of 90.14% (84.13%-94.04%).

Table 3. Overall diagnostic-accuracy estimates

Measure	Numerator/denominator	Estimate	95% CI
Sensitivity	82/86	95.35%	88.64%-98.18%
Specificity	46/56	82.14%	70.16%-90.00%
PPV	82/92	89.13%	81.14%-93.99%
NPV	46/50	92.00%	81.16%-96.85%
Accuracy	128/142	90.14%	84.13%-94.04%

Figure 1. Diagnostic-accuracy estimates with Wilson 95% confidence intervals



Stratified analyses

Table 4. Diagnostic accuracy by sex and age group

Subgroup	n	Sensitivity	Specificity	PPV	NPV	Accuracy
Female	68	95.45%	79.17%	89.36%	90.48%	89.71%
Male	74	95.24%	84.38%	88.89%	93.10%	90.54%
Age 18-40 years	62	97.14%	81.48%	87.18%	95.65%	90.32%
Age 41-65 years	80	94.12%	82.76%	90.57%	88.89%	90.00%

Sensitivity and overall accuracy were stable across the predefined strata. Confidence intervals were wider within subgroups because of smaller denominators; these analyses should therefore be interpreted as descriptive rather than evidence of equivalence.

Enhancement patterns

Among all participants, 50 (35.2%) showed no abnormal meningeal enhancement. The most frequent positive patterns were linear leptomeningeal enhancement in 25 (17.6%), diffuse leptomeningeal enhancement in 23 (16.2%), sulcal enhancement in 19 (13.4%), basal cisternal enhancement in 14 (9.9%), and cranial nerve/cisternal enhancement in 11 (7.7%).

Discussion

In this 142-participant diagnostic-accuracy study, CE-T2-FLAIR detected 82 of 86 CSF-positive cases and correctly excluded 46 of 56 CSF-negative cases. The principal finding was high sensitivity (95.35%) with moderate-to-high specificity (82.14%), producing an overall accuracy of 90.14%. The high NPV supports the sequence as a useful imaging adjunct when subtle meningeal enhancement is clinically important, although four false-negative studies show that a negative MRI cannot rule out infection.

The findings closely agree with Khalid et al., who reported 95.08% sensitivity, 82.5% specificity, and 90.1% accuracy in 101 clinically suspected cases.¹¹ Vaswani et al. reported 96% sensitivity and 85.71% specificity in a smaller cohort, while Mushtaq et al. reported 96.05% sensitivity and 92.23% specificity for tuberculous meningitis.^{6,12} The 2025 study by Sanjay et al. found 92.59% sensitivity and 94.34% accuracy and demonstrated better performance than post-contrast T1-weighted imaging.¹³ Differences in specificity across reports are plausible because meningitis type, reference criteria, contrast timing, oxygen exposure, and image interpretation vary.

The technical advantage of CE-T2-FLAIR arises from incomplete T1 shortening after gadolinium administration combined with suppression of free CSF and relatively reduced vascular signal. This creates high lesion-to-background contrast for low-grade leptomeningeal enhancement.⁶⁻¹⁰ Nevertheless, enhancement is not pathogen-specific. False-positive findings may reflect noninfectious inflammation, leptomeningeal malignancy, vascular or oxygen-related signal, motion, or prior procedures. Conversely, very early disease, low inflammatory burden, posterior fossa artifacts, or treatment before imaging may cause false-negative examinations.

Accuracy was consistent by sex and age group, suggesting that the observed performance was not confined to one demographic stratum. However, subgroup confidence intervals were wide, and no formal interaction testing was planned. The prevalence of CSF-defined infection was 60.56%; therefore, the reported predictive values are specific to a high-suspicion referral population and should not be transferred directly to screening populations with lower prevalence.

Clinical implications

CE-T2-FLAIR can be added to a contrast-enhanced brain MRI protocol at relatively low incremental acquisition cost and may improve recognition of subtle leptomeningeal disease. Its appropriate clinical role is complementary: it can support early detection, guide attention to complications, and strengthen radiological confidence, but should not delay antimicrobials or replace lumbar puncture, CSF culture, molecular testing, and clinical assessment when these are feasible.^{1,13}

Strengths and limitations

Strengths include the prespecified index-test and reference-standard definitions, complete patient-level data, consecutive sampling, a target sample derived from expected sensitivity and specificity, and presentation of confidence intervals and stratified estimates in accordance with STARD principles.^{14,15}

Several limitations require consideration. This was a single-centre study, limiting generalisability. The CSF reference definition used cellular and biochemical thresholds rather than pathogen-specific culture

or molecular confirmation, which can misclassify partially treated or noninfectious inflammatory disease. The dataset did not record causative organism, antimicrobial exposure, interval between MRI and lumbar puncture, reader blinding, inter-reader agreement, image quality, or adverse events. Only a dichotomous CE-T2-FLAIR result was evaluated, and direct within-patient comparison with contrast-enhanced T1-weighted imaging was not available. Finally, subgroup analyses had limited precision.

Conclusion

Contrast-enhanced T2-FLAIR MRI demonstrated high sensitivity and overall accuracy for infective meningitis in adults with strong clinical suspicion. The sequence is a valuable adjunct for detecting meningeal enhancement, including subtle sulcal, cisternal, and cranial-nerve patterns. A negative CE-T2-FLAIR examination does not exclude meningitis, and definitive evaluation should continue to rely on timely CSF examination and microbiological testing in the appropriate clinical context. Multicentre studies with blinded readers, standardized contrast timing, pathogen-specific reference standards, and direct comparison with contrast-enhanced T1-weighted imaging are warranted.

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