Original Article

Infectious Leptomeningitis: Diagnostic Value of Contrast-Enhanced 3D Fluid-Attenuated Inversion Recovery with Fat Suppression, Contrast-Enhanced 3D Spoiled Gradient-Echo High Resolution T1-Weighted and Contrast-Enhanced T1-Weighted Images Correlated with CSF Analysis

Tritanon O, MD[1,2], Boonsang W, MD[2], Panyaping T, MD[1,2]

[1] Advanced Diagnostic Imaging Center, Ramathibodi Hospital, Bangkok, Thailand

[2] Division of Diagnostic Neuroradiology, Department of Diagnostic and Therapeutic Radiology, Faculty of Medicine, Ramathibodi Hospital, Mahidol University, Bangkok, Thailand

Objective: To determine the diagnostic values of Contrast-Enhanced 3D Fluid-Attenuated Inversion Recovery with Fat Suppression (CE-3D FLAIR/FS), Contrast-Enhanced 3D Spoiled Gradient-Echo High Resolution T1-Weighted (CE-3D THRIVE), and Contrast-Enhanced T1-Weighted Images (CE-T1WI) in the diagnosis of infectious leptomeningitis, and if they correlated with the cerebrospinal fluid (CSF) analysis.

Materials and Methods: Fifty-six patients with clinical suspicion of infectious leptomeningitis and referred for magnetic resonance imaging (MRI) of the brain between January 2016 and December 2017 were enrolled before starting treatment. Twenty-one were diagnosed with infectious leptomeningitis, proven by CSF culture/profile, abnormal CSF cytology, or biochemical marker, and 35 had normal CSF analysis. CE-3D FLAIR/FS, CE-3D THRIVE, and CE-T1WI sequences of all patients were reviewed separately by two neuroradiologists and were determined as positive or negative for leptomeningeal enhancement or subarachnoid space abnormality. Diagnostic accuracy of each sequence was calculated and compared.

Results: The CE-3D FLAIR/FS sequence showed 100% sensitivity, 88.6% specificity, 84.0% positive predictive value (PPV), 100% negative predictive value (NPV), and 92.9% accuracy. CE-3D THRIVE revealed 76.2% sensitivity, 94.3% specificity, 88.9% PPV, 86.8% NPV, and 87.5% accuracy. CE-T1WI demonstrated 100% sensitivity, 85.7% specificity, 80.7% PPV, 100% NPV, and 91.1% accuracy. The CE-3D FLAIR/FS sequence showed the best visualization of leptomeningeal enhancement in cranial nerves (80.95%, p=0.001), followed by CE-3D THRIVE sequence (42.86%) and CE-T1WI sequence (23.81%). Nonetheless, the CE-T1WI showed statistically significant differences in detecting leptomeningeal enhancement along cerebral sulci, cerebellar folia, and cisterns compared to CE-3D FLAIR/FS and CE-3D THRIVE (p=0.012, 0.001, and 0.003).

Conclusion: All CE-3D FLAIR/FS, CE-3D THRIVE, and CE-T1WI MR sequences had high diagnostic accuracy for detection of infectious leptomeningitis without statistically significant difference. The present study showed the highest diagnostic performance on CE-3D FLAIR/FS sequence, followed by CE-T1WI and CE-3D THRIVE sequences in detecting infectious leptomeningitis. The 3D volume data in CE-3D FLAIR/FS and CE-3D THRIVE sequences was helpful to evaluate leptomeningeal enhancement along the cranial nerves.

Keywords: Infectious leptomeningitis, Leptomeningeal enhancement, Subarachnoid space abnormality, CE-3D FLAIR/FS, CE-3D THRIVE, CE-T1WI

Received 12 Dec 2019 | Revised 24 Feb 2020 | Accepted 25 Feb 2020

J Med Assoc Thai 2020;103(4):365-72
Website: http://www.jmatonline.com

Correspondence to:

Panyaping T.

Division of Diagnostic Neuroradiology, Department of Diagnostic and Therapeutic Radiology, Faculty of Medicine, Ramathibodi Hospital, Mahidol University, 270 Rama VI Road, Thung Phaya Thai, Ratchathewi, Bangkok 10400, Thailand.

Phone: +66-2-2011212, **Fax**: +66-2-2011297

Email: theephol1@gmail.com

Infectious leptomeningitis is the most common form of central nervous system (CNS) infection, which predominantly involves the arachnoid, pia, and subarachnoid space. Although the diagnosis of infectious meningitis is still based on history, physical examination, and cerebrospinal fluid (CSF) analysis,

How to cite this article: Tritanon O, Boonsang W, Panyaping T. Infectious Leptomeningitis: Diagnostic Value of Contrast-Enhanced 3D Fluid-Attenuated Inversion Recovery with Fat Suppression, Contrast-Enhanced 3D Spoiled Gradient-Echo High Resolution T1-Weighted and Contrast-Enhanced T1-Weighted Images Correlated with CSF Analysis. J Med Assoc Thai 2020;103:365-72.

there are some limitations in clinical practice.

Clinical presentation of infectious leptomeningitis may be a non-specific prodrome of fever and headache or progression to altered consciousness, focal neurologic signs, and seizures. Nuchal rigidity (stiff neck), Kernig's and Brudzinski's signs are classic signs of meningeal irritation, however, these findings may be absent or reduced in very young or elderly patients, immunocompromised individuals, or patients with a severely depressed mental status. In addition, the high prevalence of cervical spine diseases in older individuals may result in false positive tests for nuchal rigidity. Furthermore, CSF analysis could not be performed in patients who have contraindications for lumbar puncture such as brain herniation, presence of local infection at the lumbar puncture site, or coagulopathy, or patients who refuse to undergo lumbar puncture. Early diagnosis and treatment improve the patient outcome and prevent morbidity and mortality.

Magnetic resonance imaging (MRI) is one of the most sensitive imaging modalities for the diagnosis of leptomeningitis, besides the gold standard CSF analysis. Moreover, MRI has an ability to detect and follow leptomeningitis complications such as subdural empyema, cerebritis, ventriculitis, brain abscess, and infarction[1]. MRI is superior to computed tomography (CT) in the identification of active blood-brain barrier disruption and increased vascularity. It is possibly facilitating in the detection of the leptomeningeal process at an early stage that is usually underestimated on CT[2].

Leptomeningeal enhancement is usually associated with infectious meningitis. Bacterial and viral meningitis exhibit leptomeningeal enhancement that is typically thin and linear. Fungal infection appears thicker, with lumpy leptomeningeal enhancement. Leptomeningeal metastasis usually produces nodular leptomeningeal enhancement[3,4].

Fluid-attenuated inversion recovery (FLAIR) is one of the MRI pulse sequences, which is sensitive for diagnosis of subarachnoid space abnormalities and leptomeningeal diseases by nulling the hypersignal intensity of CSF using the inversion recovery pulse sequence with an inversion time[4-6].

Previous studies showed that contrast-enhanced fluid-attenuated inversion recovery (CE-FLAIR) is superior to unenhanced FLAIR in the diagnosis of leptomeningeal diseases[7]. Some prior studies revealed that CE-FLAIR images are more effective than contrast-enhanced T1-weighted images (CE-T1WI) to detect infectious leptomeningeal enhancement. The mechanism of leptomeningeal enhancement is due to breakdown of the blood-brain barrier without angiogenesis[3]. CE-FLAIR images do not demonstrate enhancement in the normal vascular structures or normal meninges that can be confused with abnormal meningeal enhancement on CE-T1WI. Additionally, CE-FLAIR is more sensitive to lower gadolinium concentrations due to its extreme sensitivity to minimal modification of the CSF composition[4,6-11]. A previous study in 3D FLAIR provided additional information for depicting the leptomeningeal diseases[12].

However, Tsuchiya et al stated that CE-T1WI results in better visibility of abscess, meningitis, cysticercosis, and epidural empyema than did FLAIR images, either with or without contrast enhancement[13]. In addition, the study by Galassi et al revealed that CE-T1WI with fat suppression is superior to CE-FLAIR imaging in most cases for depicting intracranial meningeal diseases[5].

The contrast-enhanced 3D FLAIR with fat suppression (CE-3D FLAIR/FS) provides 3D volume data with a thinner slice section, which can minimize partial volume artifact. This may help increased diagnostic yield in the detection of leptomeningitis.

Contrast-enhanced 3D spoiled gradient-echo high resolution T1-weighted images (CE-3D THRIVE) is also included in the present study because of high resolution and thin slice thickness that might help better visualization of leptomeningeal enhancement.

The purpose of the present study was to determine the diagnostic accuracy of CE-3D FLAIR/FS, CE-3D THRIVE, and CE-T1WI in the diagnosis of infectious leptomeningitis correlated with CSF analysis.

Materials and Methods

The retrospective cross-sectional study was conducted in the Department of Diagnosis and Therapeutic Radiology of Ramathibodi Hospital between January 2016 and December 2017. The study was approved by the local ethic committee.

Patients

In reviewing the medical records, presence of symptoms and signs such as headache, nuchal rigidity, fever, nausea, vomiting, altered mental status, weakness, Brudzinski's sign, and Kernig's sign, led the referring physicians to suspect infectious meningitis and patient's immune status were recorded. Detailed clinical records of these patients must be obtained with particular emphasis to diagnose the infectious meningitis.

All consecutive patients with clinical suspicion of infectious leptomeningitis referred for MRI of the brain before starting treatment at Ramathibodi Hospital between January 2016 and December 2017 were reviewed according to the criteria described below.

The patients who underwent 3T-MRI examination and had all CE-3D FLAIR/FS, CE-3D THRIVE, and CE-T1WI sequences were included. The patients were divided into two groups. The proven cases were the patients infectious leptomeningitis, identified by pathogen in the CSF culture or the CSF profile. If there was no pathogen identification, the patients that had the clinical conditions highly suggestive for leptomeningitis, typical CSF cytological findings, or biochemical markers for leptomeningitis and clinical improvement after treatment were also included in the proven cases group. The patients with normal CSF analysis, biochemical markers, and negative for other criteria in diagnosing infectious meningitis were included as the control group.

The patients with other leptomeningeal disease such as leptomeningeal metastases based on cytology, presence of acute subarachnoid hemorrhage, acute cerebral infarction, and cortical vein thrombosis, as well as the patients that underwent recent craniotomy or brain surgery were excluded.

Of the 57 patients, 21 patients were diagnosed with infectious leptomeningitis proven by CSF culture or profile, abnormal CSF cytology, or biochemical marker, and 35 patients were in the control group, which had clinical suspicion of infectious leptomeningitis, but the CSF culture, profile, or cytology were within normal limits.

Out of the 21 patients who were diagnosed with infectious meningitis, 16 patients (76.19%) had pathogen identification in CSF culture or abnormal CSF cytological findings or biochemical markers for leptomeningitis. The lumbar puncture was not performed in the other five patients (23.81%) due to impending brain herniation and the patient's denial to undergo lumbar puncture. However, they had abnormal serum biochemical markers for infectious leptomeningitis and clinical improvement after treatment.

MRI protocols and data acquisition

All MRI studies were performed on a 3T-MR scanner (Ingenia 3T; Philips Healthcare, Best, the Netherlands) with a standard head coil and obtained in CE-T1WI, CE-FLAIR, and CE-3D THRIVE sequences as a routine standard divisional protocol. A standard dose (0.1 mmol/kg) of gadolinium was injected at 1.8 to 2.0 mL/second for all patients using a standard length of IV tubing. After the contrast agent had been injected, CE-3D FLAIR/FS images were firstly performed in sagittal plane by using the following parameter: repetition time (TR) 4,800 ms, effective echo time (TEeff) 330 ms, inversion time 1,650 ms, scan time 5 minutes, field of view (FOV) 240×240 mm, matrix 368×210, and slice thickness 1.12 mm. Then, CE-3D THRIVE were performed in the axial plane with TR 5 to 7 ms, echo time (TE) 3 to 5 ms, flip angle 12°, slice thickness 1 mm, scan time 2 minutes; and CE-T1WI were lastly performed with TR 500 ms, TE 10 ms, matrix 192×240, FOV 240×240 mm, slice thickness 4 mm, and scan time 2 minutes 15 seconds.

Imaging and post-processing analysis

The axial CE-T1WI, sagittal CE-3D FLAIR/FS, and axial CE-3D THRIVE were acquired. All images were evaluated on a PACS workstation. Multiplanar reconstruction in axial, coronal, and sagittal views of the CE-3D FLAIR and CE-3D THRIVE were performed. Each sequence was reviewed separately as positive or negative for leptomeningeal enhancement by two neuroradiologists (Tritanon O) and (Panyaping T) with 7 and 8 years of experience, respectively. They were blinded to patient data, CSF results, and clinical outcomes.

The leptomeningeal enhancement or subarachnoid space abnormality was considered positive when presence of signal abnormality or enhancement in the subarachnoid space (cisterns and sulci) or along cranial nerves and was considered negative when absence of abnormal signal or enhancement in aforementioned areas. The location of the leptomeningeal enhancement was recorded as presence or absence in cerebral sulci, cerebellar folia, cisterns and cranial nerves. Presence of leptomeningeal enhancement in cerebral sulci was classified as focal when found in one lobe and diffuse when found two or more lobes. Other MR findings indicating complications of infectious meningitis such as ventriculitis, hydrocephalus, subdural empyema, cerebritis, or brain abscess were also recorded.

Statistical analysis

All statistical analyses were performed by Stata Statistical Software, version 15.1 (StataCorp LLC, College Station, TX, USA). Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and percentage accuracy of each MR

Table 1. Pathogen identification in patient with infectious meningitis

Pathogens	Number of patient (n=21)
Bacteria	
Nocardia and *Corynebacterium*	1
Streptococcus spp.	4
Virus	
Enterovirus	1
Herpes simplex virus	2
Fungus	
Cryptococcus neoformans	6
Other pathogens	
Toxoplasma gondii	4
Mycobacterium tuberculosis	2
Entamoeba histolitica	1

sequence were calculated. The presence or absence of leptomeningeal enhancement in each sequence by two neuroradiologists was determined by using the kappa analysis. Kappa value was interpreted as follows, 0.00 to 0.20 indicated slight agreement, 0.21 to 0.40 indicated fair agreement, 0.41 to 0.60 indicated moderate agreement, 0.61 to 0.80 indicated substantial agreement, and 0.81 to 1.00 indicated almost perfect agreement.

A comparison of diagnostic accuracy of leptomeningeal enhancement among the different MR sequences was performed using the receiver operating characteristic (ROC) curve and McNemar's chi-square test.

Fisher's exact and chi-square tests were used to ascertain the significant differences between presences of leptomeningeal enhancement versus MR sequences. The p-value less than 0.05 was considered significant.

Results

The pathogens of infectious meningitis were bacteria (n=5, 23.81%), virus (n=3, 14.29%), fungus (n=6, 28.57%), *Toxoplasma gondii* (n=4, 19.05%), *Mycobacterium tuberculosis* (n=2, 9.52%), and *Entamoeba histolitica* (n=1, 4.76%) (Table 1).

The sensitivity, specificity, PPV, NPV, and percentage accuracy of CE-3D FLAIR/FS and CE-3D THRIVE in the detection of infectious leptomeningitis are shown in Table 2.

Comparison of diagnostic accuracy in detecting infectious leptomeningitis among these three different MR sequences showed the highest diagnostic performance on CE-3D FLAIR/FS images, followed by CE-T1WI and CE-3D THRIVE. However, there was no statistically significant diagnostic difference among these three sequences (Table 2).

Inter-rater reliability of infectious leptomeningitis determination on CE-3D FLAIR/FS and CE-3D THRIVE sequences showed substantial agreement with kappa values of 0.67 and 0.65, respectively, while on the CE-T1WI sequences showed moderate agreement with kappa value of 0.43.

The CE-3D FLAIR/FS sequence showed the best visualization of leptomeningeal enhancement or subarachnoid space abnormality in cranial nerves (80.95%), followed by CE-3D THRIVE sequence (42.86%), and CE-T1WI sequence (23.81%) (Table 3). There was a statistically significant difference in detecting leptomeningeal enhancement or subarachnoid space abnormality along cranial nerves on CE-3D FLAIR/FS images compared to CE-3D THRIVE and CE-T1WI (Figure 1). Nonetheless, the CE-T1WI showed statistically significant difference in detecting leptomeningeal enhancement or subarachnoid space along cerebral sulci, cerebellar folia, and cisterns compared to CE-3D FLAIR/FS and CE-3D THRIVE (Table 3, Figure 2).

Beside the presence or absence of leptomeningeal enhancement, MRI findings indicating complications of infectious meningitis were also recorded and the most frequent complication was cerebritis or abscess (n=13, 61.90%). Other complications found on MRI images in the present study were hydrocephalus (n=12, 57.14%), subdural effusion or empyema

Table 2. Diagnostic accuracy of CE-3D FLAIR/FS, CE-3D THRIVE, and CE-T1WI in diagnosis of infectious leptomeningitis

MR sequences	Sensitivity (%) (95% CI)	Specificity (%) (95% CI)	PPV (%) (95% CI)	NPV (%) (95% CI)	Accuracy (%) (95% CI)	p-value
CE-3D FLAIR/FS	100 (83.89 to 100.00)	88.60 (73.26 to 96.80)	84.00 (67.61 to 92.96)	100	92.86 (82.71 to 98.02)	0.309
CE-3D THRIVE	76.20 (52.83 to 91.78)	94.30 (80.84 to 99.30)	88.90 (67.10 to 96.91)	86.80 (75.35 to 93.44)	87.50 (75.93 to 94.82)	
CE-T1WI	100 (83.89 to 100.00)	85.70 (69.74 to 95.19)	80.70 (65.10 to 90.44)	100	91.07 (80.38 to 97.04)	

CE-3D FLAIR/FS=contrast-enhanced 3D fluid-attenuated inversion recovery with fat suppression; CE-3D THRIVE=contrast-enhanced 3D spoiled gradient-echo high resolution T1-weighted image; CE-T1WI=contrast-enhanced T1-weighted image; CI=confidence interval

Table 3. Location of leptomeningeal enhancement or subarach-noid space abnormality in CE-3D FLAIR/FS, CE-3D THRIVE, and CE-T1WI

Locations	CE-3D FLAIR/FS n (%)	CE-3D THRIVE n (%)	CE-T1WI n (%)	p-value
Cerebral sulci	18 (85.71)	14 (66.67)	21 (100)	0.012*
Cerebellar folia	13 (61.90)	12 (57.14)	21 (100)	0.001*
Cisterns	16 (76.19)	9 (42.86)	19 (90.48)	0.003*
Cranial nerves	17 (80.95)	9 (42.86)	5 (23.81)	0.001*

CE-3D FLAIR/FS=contrast-enhanced 3D fluid-attenuated inversion recovery with fat suppression; CE-3D THRIVE=contrast-enhanced 3D spoiled gradient-echo high resolution T1-weighted image; CE-T1WI=contrast-enhanced T1-weighted image

* $p<0.05$ is considered statistical significance

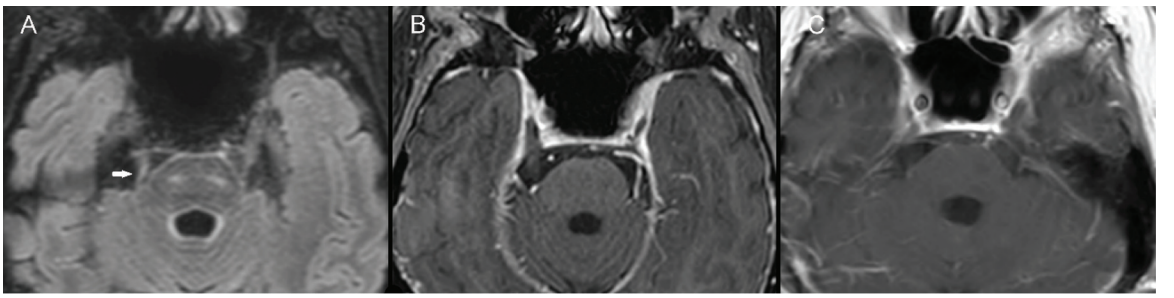

Figure 1. A 76-year-old man with cryptococcal meningitis. (A) Axial CE-3D FLAIR/FS images showed leptomeningeal enhancement along the right cranial nerve V (arrow). There was no leptomeningeal enhancement along the cranial nerve V on CE-3D THRIVE (B) or CE-T1WI (C).

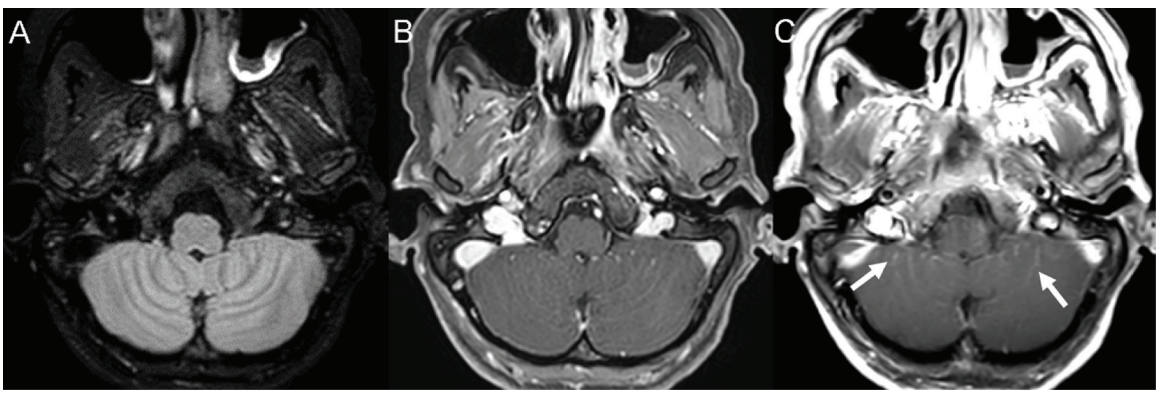

Figure 2. A 49-year-old woman with herpes simplex virus meningitis. (A) Axial CE-3D FLAIR/FS and (B) CE-3D THRIVE showed no leptomeningeal enhancement or subarachnoid space abnormality along cerebellar folia, while (C) axial CE-T1WI showed leptomeningeal enhancement along bilateral cerebellar folia (arrow).

(n=4, 19.05%,) and ventriculitis or ependymitis (n=3, 14.29%).

Discussion

Infectious leptomeningitis is a serious CNS infection, which the pathogen arrived in the CNS via hematogenous spread, local extension (e.g., sinonasal, middle ear cavities, mastoid, or dental routes), or direct implantation. MRI or CT was usually used to evaluate the complication of meningitis such as subdural empyema or effusion, ventriculitis, cerebritis, brain abscess, and cerebral infarction. The leptomeningeal inflammation was described by polymorphonuclear cell infiltration, exudate, endothelial injury, and alteration of the blood-brain barrier. The exudate occupied in subarachnoid space

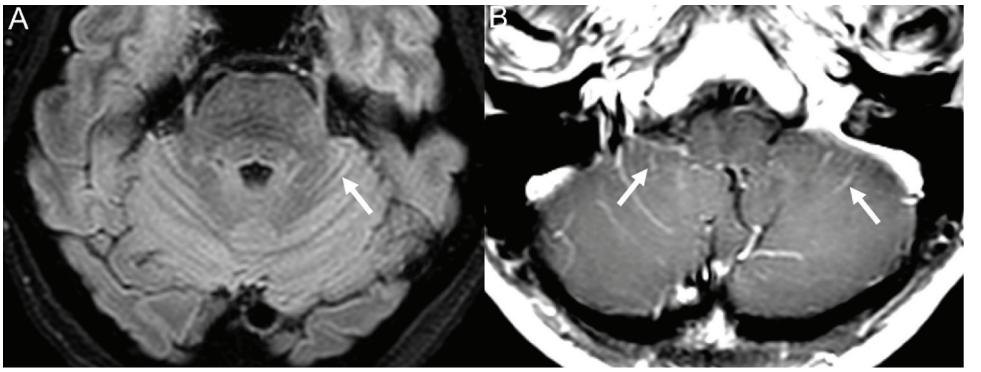

Figure 3. A 56-year-old woman with clinical suspicion of meningitis but normal CSF profile. Presence of leptomeningeal enhancement or subarachnoid space abnormality in cerebellar folia was found in CE-3D FLAIR/FS (arrow) (A) and CE-T1WI (arrow) (B).

along cerebral sulci and cistern, which was seen as abnormal signal intensity in FLAIR and contrast-enhanced sequence images[10,14]. The hyperintense signal intensity along the subarachnoid space on FLAIR images in leptomeningeal inflammation is likely due to prolongation in relaxation time related to presence of exudate or excess proteins in CSF[10,13-15]. Contrast-enhanced sequence images usually demonstrate enhancement along leptomeninges due to abnormal blood-brain barrier or vascularity[2].

The current report is the first study to describe the accuracy of CE-3D FLAIR/FS and CE-3D THRIVE sequences in the detection of leptomeningeal enhancement in infectious leptomeningitis, which show high accuracy on these two sequences similar to the most widely used conventional CE-T1WI sequence.

Despite no statistically significant difference among CE-3D FLAIR/FS, CE-3D THRIVE, and CE-T1WI sequences in the present study, the CE-3D FLAIR/FS sequence showed the highest accuracy (92.9%), followed by CE-T1WI (91.1%), and CE-3D THRIVE (87.5%) sequences for evaluation of leptomeningeal enhancement or subarachnoid space abnormality in infectious leptomeningitis (Table 2).

The previous studies by Parmar et al[7] and Splendiani et al[10], showed that CE-FLAIR sequence had similar sensitivity but higher specificity than CE-T1WI sequence for depicting infectious leptomeningitis. The results of CE-3D FLAIR/FS sequence in the authors' study were comparable and in agreement with the previous studies by Parmar et al[7] and Splendiani et al[10]. The prior study conducted by Vaswani et al[11] also suggested the superiority of CE-FLAIR sequence in detecting infectious leptomeningitis with higher sensitivity and specificity over CE-T1WI sequence. However, the present study performed thinner MRI sections and additional 3D volume data with fat suppression technique on FLAIR sequence, which gave high accuracy and reduced the partial volume artifact.

In the present study, the CE-3D THRIVE sequence had the highest specificity and positive predictive value but the lowest sensitivity, negative predictive value and percentage accuracy compared to the CE-3D FLAIR/FS, and CE-T1WI sequences. There were five false negative cases with absence leptomeningeal enhancement or subarachnoid space abnormality on CE-3D THRIVE sequence but there was presence in CE-3D FLAIR/FS and CE-T1WI sequences. No false negative case was found on CE-3D FLAIR/FS and CE-T1WI sequences. These could be explained by minimal degree of leptomeningeal enhancement on CE-3D THRIVE was difficult to distinguish from normal enhancement of vessels in subarachnoid space.

The present study showed the benefit of CE-3D FLAIR/FS and CE-3D THRIVE sequences for significantly better detection of leptomeningeal enhancement or subarachnoid space abnormality along cranial nerves than on the CE-T1WI sequence (Table 3). Their 3D volume data and thin slice thickness gave more information to reassure the interpretation of leptomeningeal enhancement along the cranial nerve. However, the CE-T1WI sequence showed the best visualization in detecting leptomeningeal enhancement in cerebral sulci, cerebellar folia, and cisterns with statistical significance.

In the four false positive cases on the CE-3D FLAIR/FS sequence and the two false positive cases on the CE-3D THRIVE sequence, leptomeningeal enhancement or subarachnoid space abnormality was

present in bilateral cerebellar folia. Whereas all false positive cases on the CE-T1WI sequence showed leptomeningeal enhancement in both cerebral sulci and cerebellar folia (Figure 3). This could be due to CSF pulsation artifact in the posterior fossa region on CE-3D FLAIR/FS and prominent vessels in cerebellar folia on CE-3D THRIVE and CE-T1WI sequences.

Furthermore, the CE-T1WI sequence in the present study showed moderate agreement in determining leptomeningeal enhancement between two experienced neuroradiologists while both CE-3D FLAIR/FS and CE-3D THRIVE sequences showed substantial agreement. This could be described by more partial volume artifact on CE-T1WI sequence with 4-mm slice thickness than on CE-3D FLAIR/FS and CE-3D THRIVE sequences with 1-mm slice thickness, which might lead to the different interpretation.

Limitation in the present study was that not all the patients that were suspected of infectious meningitis underwent for MRI. Most of the cases in the present study were immunocompromised, who received the MRI to monitor the complications of meningitis or to evaluate for other CNS infections. Therefore, pathogens identified in the present study did not literally represent the true incidence in general population particularly in bacterial meningitis, which was found in only five cases (23.81%).

Conclusion

All CE-3D FLAIR/FS, CE-3D THRIVE, and CE-T1WI MR sequences have high diagnostic accuracy for detection of infectious leptomeningitis without statistically significant difference. The present study showed the highest diagnostic performance on CE-3D FLAIR/FS sequence, followed by CE-T1WI and CE-3D THRIVE sequences in detecting infectious leptomeningitis. The 3D volume data in CE-3D FLAIR/FS and CE-3D THRIVE sequences were helpful to evaluate leptomeningeal enhancement along the cranial nerves.

What is already known on this topic?

The MRI characteristics of infectious leptomeningitis on CE-3DFLAIR/FS, CE-3D THRIVE, and CE-T1WI sequences.

What this study adds?

This study showed diagnostic accuracy of CE-3D FLAIR/FS, CE-T1WI, and CE-3D THRIVE sequences as 100% sensitivity, 88.6% specificity, 84.0% PPV, 100% NPV, and 92.9% accuracy, 76.2% sensitivity, 94.3% specificity, 88.9% PPV, 86.8% NPV, and 87.5% accuracy, and 100% sensitivity, 85.7% specificity, 80.7% PPV, 100% NPV, and 91.1% accuracy, respectively.

CE-3D FLAIR/FS sequence has the highest diagnostic performance followed by CE-T1WI and CE-3D THRIVE sequences for detection of leptomeningeal enhancement in infectious leptomeningitis.

The 3D volume data in CE-3D FLAIR/FS and CE-3D THRIVE sequences is helpful to evaluate leptomeningeal enhancement along the cranial nerves.

Acknowledgement

The authors would like to thank Miss Sukanya Siriyotha, Department of clinical epidemiology and biostatistics, Ramathibodi Hospital, for assistance with statistical analysis.

Ethic consideration

The study was approved by Ethic Committee of Faculty of Medicine, Ramathibodi Hospital.

Conflicts of interest

The authors declare no conflict of interest.

References

1. Hughes DC, Raghavan A, Mordekar SR, Griffiths PD, Connolly DJ. Role of imaging in the diagnosis of acute bacterial meningitis and its complications. Postgrad Med J 2010;86:478-85.
2. Chang KH, Han MH, Roh JK, Kim IO, Han MC, Kim CW. Gd-DTPA-enhanced MR imaging of the brain in patients with meningitis: comparison with CT. AJR Am J Roentgenol 1990;154:809-16.
3. Smirniotopoulos JG, Murphy FM, Rushing EJ, Rees JH, Schroeder JW. Patterns of contrast enhancement in the brain and meninges. Radiographics 2007;27:525-51.
4. Lee EK, Lee EJ, Kim S, Lee YS. Importance of contrast-enhanced fluid-attenuated inversion recovery magnetic resonance imaging in various intracranial pathologic conditions. Korean J Radiol 2016;17:127-41.
5. Galassi W, Phuttharak W, Hesselink JR, Healy JF, Dietrich RB, Imbesi SG. Intracranial meningeal disease: comparison of contrast-enhanced MR imaging with fluid-attenuated inversion recovery and fat-suppressed T1-weighted sequences. AJNR Am J Neuroradiol 2005;26:553-9.
6. Singer MB, Atlas SW, Drayer BP. Subarachnoid space disease: diagnosis with fluid-attenuated inversion-recovery MR imaging and comparison with gadolinium-enhanced spin-echo MR imaging--blinded reader study. Radiology 1998;208:417-22.

7. Parmar H, Sitoh YY, Anand P, Chua V, Hui F. Contrast-enhanced flair imaging in the evaluation of infectious leptomeningeal diseases. Eur J Radiol 2006;58:89-95.
8. Ahmad A, Azad S, Azad R. Differentiation of leptomeningeal and vascular enhancement on post-contrast FLAIR MRI sequence: role in early detection of infectious meningitis. J Clin Diagn Res 2015;9:TC08-12.
9. Melhem ER, Bert RJ, Walker RE. Usefulness of optimized gadolinium-enhanced fast fluid-attenuated inversion recovery MR imaging in revealing lesions of the brain. AJR Am J Roentgenol 1998;171:803-7.
10. Splendiani A, Puglielli E, De Amicis R, Necozione S, Masciocchi C, Gallucci M. Contrast-enhanced FLAIR in the early diagnosis of infectious meningitis. Neuroradiology 2005;47:591-8.
11. Vaswani AK, Nizamani WM, Ali M, Aneel G, Shahani BK, Hussain S. Diagnostic accuracy of contrast-enhanced flair magnetic resonance imaging in diagnosis of meningitis correlated with CSF analysis. ISRN Radiol 2014;2014:578986.
12. Fukuoka H, Hirai T, Okuda T, Shigematsu Y, Sasao A, Kimura E, et al. Comparison of the added value of contrast-enhanced 3D fluid-attenuated inversion recovery and magnetization-prepared rapid acquisition of gradient echo sequences in relation to conventional postcontrast T1-weighted images for the evaluation of leptomeningeal diseases at 3T. AJNR Am J Neuroradiol 2010;31:868-73.
13. Tsuchiya K, Inaoka S, Mizutani Y, Hachiya J. Fast fluid-attenuated inversion-recovery MR of intracranial infections. AJNR Am J Neuroradiol 1997;18:909-13.
14. Lummel N, Koch M, Klein M, Pfister HW, Bruckmann H, Linn J. Spectrum and Prevalence of Pathological Intracranial Magnetic Resonance Imaging Findings in Acute Bacterial Meningitis. Clin Neuroradiol 2016; 26:159-67.
15. Kamran S, Bener AB, Alper D, Bakshi R. Role of fluid-attenuated inversion recovery in the diagnosis of meningitis: comparison with contrast-enhanced magnetic resonance imaging. J Comput Assist Tomogr 2004;28:68-72.