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ABSTRACT

PURPOSE: To determine the accuracy of MR imaging for diagnosis of meningitis in infants.

MATERIALS AND METHODS: Retrospective review of infants less than 1 year of age who underwent a brain MR imaging for meningitis from 2010–2018. Gold standard for diagnosis of bacterial meningitis was a positive bacterial CSF culture or a positive blood culture with an elevated CSF WBC count, and diagnosis of viral meningitis was a positive CSF PCR result and elevated CSF WBC count. Sensitivity, specificity, PPV, NPV, and accuracy for MR imaging diagnosis of meningitis were calculated.

RESULTS: Two hundred nine infants with mean age 80 days (range 0–347 days) were included. There were 178 true positives with the most common pathogens being: *Group B Streptococcus* (58), *E. coli* (50), *Streptococcus pneumoniae* (21), *H. influenzae* (4); Herpes simplex virus 1 or 2 (18); Enterovirus (4); and other (23). There were 31 true negatives. Range of sensitivity, specificity, PPV, NPV, and accuracy of MR imaging for detection of meningitis was 67.4–83.5%, 92.3–95.7%, 95.0–98.6%, 33.3–76.5%, and 71.3–86.5% respectively. MR imaging sensitivity decreased after 10 days from time of presentation while specificity remained stable. Among individual MR imaging findings, leptomeningeal enhancement was the most sensitive finding, while cerebritis, infarction, ventriculitis, abscess, and intraventricular purulent material were the most specific findings.

CONCLUSIONS: MR imaging of the brain demonstrates high specificity and moderate sensitivity for diagnosis among infants presenting with signs and symptoms of meningitis. The results reflect current standard of care for imaging of infants with meningitis however a selection bias for imaging of more severe meningitis may affect these results.

ABBREVIATIONS: NPV = negative predictive value; PCR = polymerase chain reaction; PPV = positive predictive value; WBC = white blood cell

Bacterial and viral CNS infections are common in infants and can present with various nonspecific signs and symptoms, including fever, hypothermia, irritability, poor feeding, bulging fontanelle, and seizures. Bacterial meningitis is an inflammation of the meninges affecting the pia and arachnoid and subarachnoid spaces in response to bacteria and/or bacterial products and is most common in the first year of life.[1,2] In infants, bacteria and viruses can enter the body through the skin, mucosa, blood, and respiratory and gastrointestinal tracts. They most commonly enter the CNS by the hematogenous route and, less commonly, by direct spread from adjacent sites such as the sinuses or mastoids. In the modern era, the mortality from bacterial meningitis is approximately 10%, and survivors remain at high risk for neurologic sequelae.[3,4] In neonates, the most common pathogens causing bacterial meningitis are *Group B Streptococcus* and *Escherichia coli*, while *Streptococcus pneumoniae* is the most common cause in infants.[1,5] The most common causes of viral meningitis in neonates and infants are herpes simplex and Enterovirus; however, many viral infections remain undiagnosed due to limitations in laboratory testing.

The diagnosis of bacterial or viral meningitis relies on isolation in a culture or detection by molecular testing of the causative pathogen from the CSF. Patients with potential meningitis will often undergo an MR imaging of the brain to assess imaging findings supportive of a CNS infection and complications that can include abscess, empyema, arterial or venous infarction, and hydrocephalus/CSF circulation disorders. However, the exact diagnostic accuracy of MR imaging for the detection of meningitis in infants remains unknown. In addition, it is unknown which MR imaging findings are the most sensitive or specific for the diagnosis of meningitis and whether the length of time from presentation to MR imaging affects the diagnostic sensitivity of MR imaging.

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Therefore, the purpose of this study was to determine the diagnostic accuracy of MR imaging for the diagnosis of meningitis among infants and determine which factors affect the diagnostic performance of MR imaging.

MATERIALS AND METHODS

Following institutional review board approval (Texas Children's Hospital), a retrospective review was performed from 2010 to 2018 among infants younger than 1 year of age who presented with signs and symptoms of meningitis, including any combination of fever, seizure, lethargy, respiratory distress, decreased oral intake, or irritability. All patients had a lumbar puncture with CSF laboratory data, CSF culture, anaerobic and aerobic blood cultures, and an MR imaging of the brain performed without and with IV contrast within 30 days of presentation. The timing from when CSF was obtained with respect to administration of IV antibiotics and acyclovir was recorded as either before administration, <24 hours after administration, or >24 hours after administration. The age (including neonate age range defined as age <30 days) and prematurity (defined as <37 gestational weeks) of the patients were extracted from the electronic medical records. Because of the retrospective nature of this study, decision to perform an MR imaging was based on standard clinical care and at our institution this includes routine MR imaging for infants less than 6 weeks and after 6 weeks is based on physician judgment of severity or potential for complications of meningitis.

The criterion standard diagnosis of bacterial meningitis was determined by either a CSF culture positive for meningitis or a blood culture positive for meningitis combined with elevated CSF white blood cell (WBC) count (>20 WBC/μL for younger than 30 days of age, >9 WBC/μL for 30–90 days of age, and >6 WBC/μL for older than 90 days of age).[6] The criterion standard diagnosis of viral meningitis was a viral polymerase chain reaction (PCR) from CSF with positive findings and an elevated CSF WBC count. Patients with true-negative findings had a normal CSF WBC count and a CSF culture and CSF PCR testing with negative findings. A total of 42 patients with CSF WBC counts above the normal range but without a CSF culture, blood culture, or viral PCR positive for meningitis were excluded from analysis. CSF cultures with coagulase-negative staphylococci or other skin contaminants were excluded. Patients with no CSF sampling, immunodeficiency, malignancy, or presence of an intracranial shunt were also excluded.

MR imaging of the brain was performed in all patients on 1.5T and 3T MR imaging scanners using standard departmental protocols including precontrast axial and sagittal 2D T1-weighted TSE with 3- to 4-mm section thickness, axial 2D FLAIR with 3- to 4-mm section thickness, axial and coronal 2D T2-weighted TSE with 2.5- to 4-mm section thickness, axial gradient-echo or SWI with 2.5- to 4-mm section thickness, axial DWI/DTI with 2.5- to 4-mm section thickness, and postcontrast axial and coronal 2D T1-weighted imaging with 3- to 4-mm section thickness with the axial imaging performed immediately after intravenous contrast administration followed by the coronal imaging. The TE/TR times varied by scanner with T1W MRI TE/TR ranging from 10–12.5 ms/458–533 ms and T2W MRI TE/TR times ranging from 80–120 ms/3074–7000ms. Standard of care at our institution is to perform post contrast imaging in patients with suspected meningitis unless standard contraindications existed such as renal failure or contrast allergy.

Retrospective independent blinded reviews of initial brain MRIs performed without and with intravenous contrast were performed by 2 board-certified neuroradiologists (S.K., and M.K.) with, respectively, 10 and 13 years of experience in pediatric neuroradiology, for the presence of direct signs of meningitis, including leptomeningeal enhancement, ventriculitis, cerebritis, infarction, abscess/granuloma, and extra-axial (subarachnoid or subdural spaces) or intraventricular purulent material. Representative examples of these findings are shown in Fig 1. These findings are considered most typical for intracranial infection in patients presenting with signs and symptoms of meningitis.[7-12] The neuroradiologists reviewed the MRIs of the brain with the clinical indication of possible meningitis but were blinded to the CSF analysis results and pathogen diagnosis.

Meningeal enhancement was defined as abnormal/increased contrast enhancement of the leptomeninges on postcontrast T1-weighted imaging. Ventriculitis was defined as contrast enhancement of the ependymal surface of the ventricles on postcontrast T1-weighted imaging. Cerebritis was defined as cortical contrast enhancement on postcontrast T1-weighted imaging or diffusion restriction or edema as indicated by T2/FLAIR hyperintense signal in a nonvascular distribution involving the cortex. Infarction was defined as diffusion restriction in an arterial or venous vascular distribution in either a wedge-shaped cortical distribution or a lacunar infarct pattern. Abscess was defined as a peripherally enhancing intraparenchymal lesion on postcontrast T1-weighted imaging with or without associated diffusion restriction. Granuloma was defined as a homogeneously enhancing parenchymal lesion on postcontrast T1-weighted imaging. Extra-axial purulent material was defined as extra-axial (subarachnoid, subdural, or epidural space) diffusion restriction not caused by hemorrhage as indicated by a lack of susceptibility artifacts or T1-shortening. Intraventricular purulent material was defined as diffusion restriction within the ventricles not caused by hemorrhage as indicated by a lack of susceptibility artifacts or T1-shortening. Additional findings that are considered indirect signs or complications of meningitis were recorded, including hydrocephalus, dural sinus thrombosis, and hemorrhage.

For all patients in whom there was a discordant MR imaging finding, the reviewers reached a consensus on the finding, and this consensus was used as the final diagnosis. Interobserver agreement for individual MR imaging findings was calculated using the κ statistic. A κ value of 0.81–1.0 indicated excellent agreement; 0.61–0.80, good agreement; 0.41–0.60, moderate agreement; 0.21–0.40, fair agreement; and 0–0.20, slight agreement.

An MR imaging diagnosis positive for meningitis was defined as any combination of leptomeningeal enhancement, ventriculitis, extra-axial or intraventricular purulent material, or cerebritis. Subsequently, the sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy of an MR imaging diagnosis of meningitis was calculated for the initial MRIs of the brain performed within 1, 3, 7, 10, 14, 21, and 30 days of the initial presentation. Following these calculations, the timeframe of brain MRIs performed within 7 days of presentation (the timeframe that demonstrated the greatest accuracy) was chosen to subsequently determine the accuracy of indirect MR imaging findings, the effects of the timing of antibiotic and acyclovir administration,

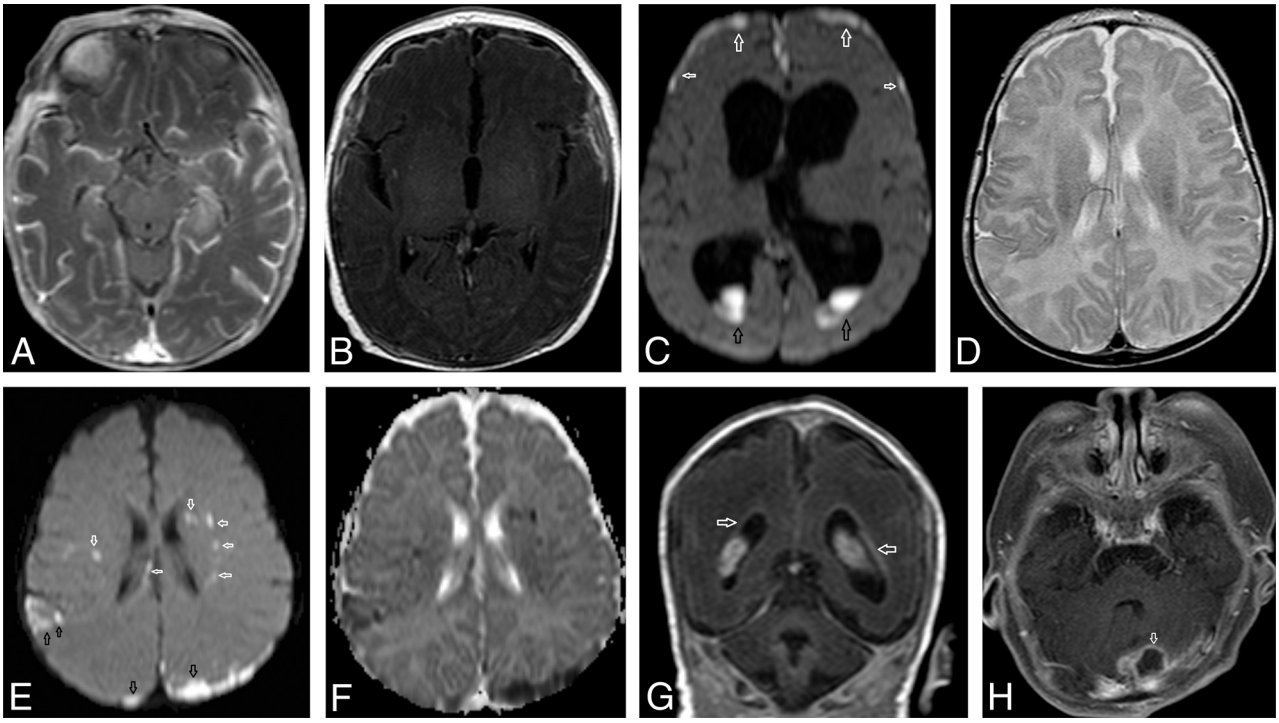

FIG 1. Representative examples of direct MR imaging findings of meningitis. *A* and *B*, Axial postcontrast T1-weighted images in 2 separate patients with herpes simplex virus meningitis and Group B streptococcal meningitis, respectively, demonstrating abnormal leptomeningeal enhancement indicative of meningitis. *C*, Axial DWI demonstrates restricted diffusion (ADC not shown) in the occipital horns of the lateral ventricles indicative of intraventricular purulent material (*black arrows*) and extra-axial diffusion restriction, indicative of extra-axial purulent material (*white arrows*). *D–F*, Axial T2-weighted imaging, axial DWI, and an axial ADC map demonstrate focal areas of restricted diffusion in the caudate head, periventricular WM, and corona radiata, indicative of acute lacunar infarctions (*white arrows*), and cortical areas of diffusion restriction and T2 hyperintensity, indicative of cerebritis (*black arrows*). *G*, Coronal postcontrast T1-weighted image demonstrates ependymal enhancement, indicative of ventriculitis (*white arrows*). *H*, Axial postcontrast T1-weighted image demonstrates a peripherally enhancing fluid (*arrow*) with restricted diffusion (not shown), indicative of an abscess.

Table 1: Patient demographics

Demographics	
Total No. of patients	209
Age	80 days (range, 0–347 days)
Male/female ratio	126:83
Prematurity	19% (39/209)
Most common presenting signs and symptoms	
Fever	75% (156/209)
Vomiting/decreased oral intake	27% (57/209)
Seizure	22% (47/209)
Apnea/respiratory distress	18% (37/209)
Irritability	21% (44/209)
Lethargy	12% (26/209)
Rash	4% (9/209)

prematurity, and age (neonate versus non-neonate age) on the diagnostic performance of MR imaging and to evaluate the diagnostic performance of individual MR imaging findings. Last, a Fisher exact test was used to compare direct MR imaging findings of meningitis found in bacterial-versus-viral meningitis. A P value $< .05$ was considered statistically significant.

RESULTS

Patient demographics are shown in Table 1. Two hundred nine infants with a mean age 80 days (range, 0–347 days) were included. The mean days from presentation to lumbar puncture were 0.9 (SD, 1.6) days. The mean difference between date of symptom onset and date of presentation was 0.6 days (range 0–3 days). There were a total of 178 cases of meningitis (true-positives). Bacterial meningitis pathogens included the following: *Group B Streptococcus* ($n = 58$); *E coli* ($n = 50$); *S pneumoniae* ($n = 21$); *Haemophilus Influenza* ($n = 4$); *Neisseria meningitides* ($n = 3$); *Enterobacter* ($n = 3$); *Enterococcus* ($n = 3$); *Streptococcus bovis* ($n = 2$); *Citrobacter* ($n = 2$); *Salmonella* ($n = 2$); *Streptococcus pyogenes* ($n = 2$); *Streptococcus infantarius* ($n = 1$); *Proteus mirabilis* ($n = 1$); *Pseudomonas aeruginosa* ($n = 1$); *Klebsiella* ($n = 1$); *Acinetobacter* ($n = 1$); *Serratia* ($n = 1$). Viral pathogens included herpes simplex 1 or 2 ($n = 18$) and Enterovirus ($n = 4$).

There was excellent interobserver agreement for all direct MR imaging findings of meningitis as follows: leptomeningeal enhancement, 0.85 (95% CI, 0.74–0.95); cerebritis, 0.90 (95% CI, 0.78–1.0); ventriculitis, 0.91 (95% CI, 0.80–1.0); abscess, 1.0 (95% CI, 1.0–1.0); infarction, 0.95 (95% CI, 0.89–1.0); extra-axial purulent material, 0.90 (95% CI, 0.81–0.99); and intraventricular purulent material, 0.96 (95% CI, 0.89–1.0).

The diagnostic performance of brain MRIs with respect to the time from presentation is shown in Table 2. Overall, brain MRIs demonstrated high specificity and moderate sensitivity. The range of diagnostic performance of MR imaging for the detection of meningitis was the following: sensitivity, 70.5%–83.5%;

Table 2: MR imaging diagnosis of meningitis with respect to time[a]

Time from Presentation to MR Imaging	No. of Patients	Sensitivity	Specificity	PPV	NPV	Accuracy
1 day	37	82.6% (61.2%–95.1%)	92.9% (66.1%–99.8%)	95.0% (74.0%–99.2%)	76.5% (56.9%–88.9%)	86.5% (71.2%–95.5%)
3 days	69	80.0% (66.3%–90.0%)	94.4% (72.7%–99.9%)	97.6% (85.6%–99.6%)	63.0% (49.1%–75.0%)	83.8% (72.9%–91.6%)
7 days	108	83.5% (73.9%–90.7%)	95.7% (78.1%–99.9%)	98.6% (91.2%–99.8%)	61.1% (49.0%–72.2%)	86.1% (78.1%–92.0%)
10 days	119	80.7% (71.2%–88.1%)	92.3% (74.9%–99.1%)	97.4% (90.8%–99.3%)	57.1% (46.5%–67.2%)	83.2% (75.2%–89.4%)
14 days	157	75.8% (67.4%–82.9%)	93.1% (77.23%–99.2%)	98.0% (92.7%–99.5%)	46.6% (38.7%–54.6%)	79.0% (71.8%–85.1%)
21 days	197	70.5% (62.9%–77.3%)	93.6% (78.6%–99.2%)	98.3% (93.9%–99.6%)	37.2% (31.5%–43.2%)	74.1% (67.4%–80.1%)
30 days	209	67.4% (60.0%–74.2%)	93.6% (75.6%–99.2%)	98.4% (94.0%–99.6%)	33.3% (28.4%–38.6%)	71.3% (64.7%–77.3%)

Note:—True positives/True negatives for each time frame as follows: 1 day (19/13), 3 days (41/17), 7 days (71/22), 10 days (75/24), 14 days (97/27), 21 days (117/29), 30 days (178/29).
[a] Numbers in parentheses are 95% confidence intervals.

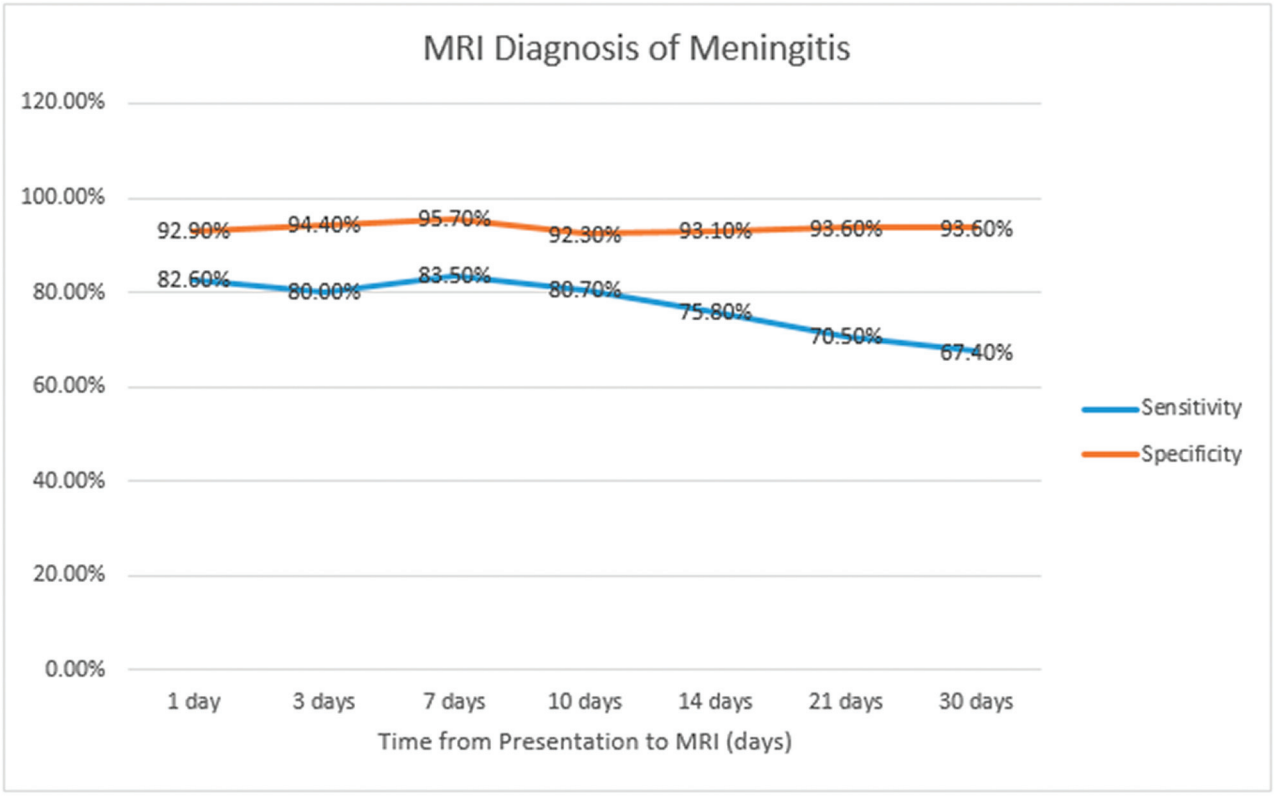

FIG 2. MR imaging diagnosis of meningitis relative to the time from presentation to MR imaging.

specificity, 92.9%–95.7%; PPV, 95.0%–98.6%; NPV, 33.3%–76.5%; and accuracy, 71.3%–86.5%. Although there was overlap of the 95% confidence intervals, there was a trend toward decreasing sensitivity but consistent specificity as the duration of time increased from clinical presentation to brain MR imaging as seen in Fig 2.

Because MRIs performed within 7 days showed the highest accuracy, this timeframe was chosen to evaluate additional factors. Diagnostic performance of individual MR imaging findings is shown in Table 3. Among individual MR imaging findings, leptomeningeal contrast enhancement was the most sensitive finding (73.3%), while cerebritis, infarction, ventriculitis, abscess, and intraventricular purulent material were the most specific findings (100%). For MRIs performed within 7 days of presentation, the sensitivity and specificity for patients receiving antibiotics before CSF ($n = 39$) versus after CSF ($n = 70$) were 86% (95% CI, 66%–95%) and 91% (95% CI, 57%–99%) versus 83% (95% CI, 70%–91%) and 92% (95% CI, 62%–100%). For MRIs performed within 7 days of presentation, the sensitivity and specificity for neonates ($n = 37$) versus non-neonates ($n = 72$) was 76% (95% CI, 56%–89%) and 88% (95% CI, 47%–99%) versus 88% (95% CI, 75%–94%) and 94% (95% CI, 68%–100%). For MRIs performed within 7 days of presentation, the sensitivity and specificity for premature infants ($n = 15$) versus full-term infants ($n = 94$) was 81% (95% CI, 48%–97%) and 100% (95% CI, 40%–100%) versus 84% (95% CI, 73%–91%) and 90% (95% CI, 67%–98%). Last, for MRIs within 7 days of presentation, indirect findings and complications of meningitis including hydrocephalus, dural sinus thrombosis, and hemorrhage demonstrated a sensitivity and specificity of 78% and 62%, respectively, for the diagnosis of meningitis, indicating an expected reduced accuracy compared with direct MR imaging findings of meningitis.

Table 3: Diagnostic performance of individual MR imaging findings for the diagnosis of meningitis[a]

MR Imaging Findings	Sensitivity	Specificity	PPV	NPV	Accuracy
Leptomeningeal enhancement	73.3% (62.6%–82.2%)	78.1% (78.1%–99.9%)	98.4% (90.2%–99.7%)	48.9% (40.0%–57.8%)	78.0% (69.0%–85.4%)
Ventriculitis	13.8% (7.3%–22.9%)	100% (84.6%–100%)	100% (100%)	22.7% (21.2%–24.2%)	31.2% (22.7%–40.8%)
Cerebritis	28.7% (19.5%–39.4%)	100% (84.6%–100%)	100% (100%)	26.2% (23.7%–28.9%)	43.1% (33.7%–53.0%)
Infarct	43.7% (33.1%–54.7%)	100% (84.6%–100%)	100% (100%)	31.0% (27.2%–35.1%)	55.1% (45.2%–64.6%)
Extra-axial purulent material	32.6% (22.8%–43.5%)	95.7% (78.1%–99.9%)	96.6% (80.1%–99.5%)	27.5% (24.2%–31.0%)	36.3% (36.3%–55.7%)
Intraventricular purulent material	13.8% (7.3%–22.9%)	100% (84.6%–100%)	100% (100%)	22.7% (21.2%–24.2%)	31.2% (22.7%–40.8%)
Abscess/granuloma	2.3% (0.28%–8.1%)	100% (84.6%–100%)	100% (100%)	20.6% (20.0%–21.1%)	22.0% (14.7%–31.0%)

[a] Numbers in parentheses are 95% confidence intervals. Data were obtained from brain MRIs within 7 days of presentation.

Table 4: Diagnostic performance of MR imaging findings for the diagnosis of bacterial and viral meningitis[a]

MR Imaging Findings	Sensitivity	Specificity	PPV	NPV	Accuracy
Bacterial	87.9% (77.5%–94.6%)	95.7% (78.1%–99.9%)	98.3% (89.5%–99.8%)	73.3% (58.8%–84.1%)	89.9% (81.7%–95.3%)
Viral	73.3% (44.9%–92.2%)	95.7% (78.1%–99.9%)	91.7% (61.2%–98.7%)	84.6% (70.2%–92.8%)	86.8% (71.9%–95.6%)

[a] Numbers in parentheses are 95% confidence intervals. Data were obtained from brain MRIs within 7 days of presentation.

The diagnostic performance for the detection of bacterial and viral meningitis is shown in Table 4. Although there is overlap in the 95% confidence intervals between the groups, there was a trend toward higher sensitivity for the detection of bacterial meningitis compared with viral meningitis. Differences in the detection of individual direct MR imaging findings for patients with bacterial meningitis versus viral meningitis are as follows: leptomeningeal enhancement, 54% (84/156) versus 36% (8/22) ($P = .17$); extra-axial purulent material, 38% (60/156) versus 0% (0/22) ($P < .0001$); intraventricular purulent material, 15% (24/156) versus 0% (0/22) ($P = .048$); ventriculitis, 12% (19/156) versus 9% (2/22) ($P = 1.0$); infarction, 28% (43/156) versus 36% (8/22) ($P = .45$); cerebritis, 17% (26/156) versus 36% (8/22) ($P = .13$); and abscess, 1% (2/156) versus 0% (0/22) ($P = 1.0$).

DISCUSSION

In this study, we evaluated the accuracy of MR imaging for the detection of meningitis in infants and evaluated which factors may affect the accuracy of MR imaging. The results of this study demonstrate that MR imaging has a high specificity and PPV but moderate sensitivity for the diagnosis of meningitis in infants. MR imaging retains the high level of specificity, even with an increasing length of time from presentation. Conversely, the sensitivity of MR imaging appears to decrease with time after approximately 10 days. Prematurity, neonatal age, and administration of antibiotics or acyclovir before obtaining CSF do not appear to affect the accuracy of MR imaging; however, the sensitivity of MR imaging may be lower for viral meningitis compared with bacterial meningitis.

Although CSF laboratory and culture remain the criterion standard for diagnosis, these results provide useful clinical information and quantitative data for the long-held clinical notion regarding the utility of MR imaging for the diagnosis of meningitis. These results quantitatively demonstrate the percentage of false-negative MRIs in patients with CSF culture or PCR-confirmed meningitis, supporting the established practice of CSF analysis, culture, and PCR for diagnosis. The results are also useful for other frequent clinical scenarios in which the diagnosis of meningitis is uncertain. In some patients, CSF can be difficult to obtain at presentation, and in these patients, MR imaging could be performed to assess meningitis and provide information supportive of the diagnosis. Other patients may have a CSF culture with negative findings, a blood culture with positive findings, and a borderline or elevated CSF WBC count. In these patients, an MR imaging with positive findings would support the diagnosis of meningitis because the PPV is >95%, while an MR imaging with negative findings could be better understood as indeterminate because the NPV ranges from 33% to 77%. As both PPV and NPV are dependent on the prevalence of disease, a PPV in the setting of high prevalence generally has less utility but for serious infections from meningitis this would still retain its value. We chose to exclude patients with elevated CSF WBC count but negative culture and PCR results because additional factors including CSF glucose and protein values, and whether the infant was pretreated with antibiotics influences our physicians whether to continue to treat or not treat as meningitis. For this reason and our definition of gold standard diagnosis of meningitis, these patients were excluded.

We evaluated the various factors that may affect an MR imaging diagnosis of meningitis. The duration from presentation to MR imaging affects its accuracy. Sensitivity decreases with time while the specificity remains at a consistently high level. While it is unlikely that MR imaging would be used for diagnosing meningitis at 30 days from presentation, the results form a better understanding of the evolution of imaging findings, but further research is needed for better understanding the expected duration for which MR imaging findings persist. Other factors including antibiotic and acyclovir administration before obtaining CSF, prematurity, and neonatal age were evaluated but did not alter the sensitivity and specificity of MR imaging when performed with in 7 days of presentation. Last, we compared MR imaging findings in patients with bacterial and viral pathogens. As expected, extra-axial purulent material, intraventricular purulent material, and abscess were found only with bacterial meningitis and not in viral meningitis. Meanwhile, leptomeningeal enhancement, cerebritis, infarction, and ventriculitis were found with both bacterial and viral meningitis.

There are several limitations of this study. First, this was a single-center, retrospective study, so external validity may be limited. The inclusion criteria create a potential selection bias because patients with less severe disease may not be imaged but reflect the current clinical practice. Another potential limitation of this study is the subjectivity in the determination of individual MR imaging findings. This subjectivity was mitigated by independent imaging reviews by 2 experienced pediatric neuroradiologists, consensus diagnosis in discordance findings, and calculation of interobserver agreement. We observed excellent interobserver agreement for all MR imaging findings. Although some of the MR imaging findings could be seen in diseases other than meningitis such as leptomeningeal enhancement with malignancy, this study was performed among patients with signs and symptoms of meningitis, many of whom will present with fever. This clinical context is necessary, and extrapolation of these results to other clinical scenarios should be avoided.

Another potential limitation is the lack of a postcontrast FLAIR imaging of the brain. Postcontrast FLAIR may increase the sensitivity for the detection of leptomeningeal enhancement, which may improve the sensitivity of MR imaging.[13-16] Because our institution does not routinely use postcontrast FLAIR imaging, these data were not available in all patients and, therefore, could not be included in this study. Further research assessing the accuracy of MR imaging, including the use of postcontrast FLAIR, would be valuable because this may further increase the sensitivity of MR imaging. Another limitation is the exclusion of patients with a CSF culture and blood culture with negative findings but with an elevated CSF WBC count. These patients represent a substantial number of patients and are a challenge with regard to clinical decision-making about treatment. Because this study required a criterion standard for comparison with MR imaging, we did not evaluate the role of MR imaging in these patients. One could extrapolate, however, that given the high PPV of MR imaging, an MR imaging with positive findings in these patients could be considered evidence of meningitis. Similarly, we used CSF or blood culture and CSF PCR testing as criterion standards; however, these tests may have limitations in the detection of meningitis, and although this represents standard clinical care, it could impact our results. In particular, the detection of viral causes of meningitis is likely to be incomplete so that the accuracy of MR imaging should be reassessed if further advances in laboratory testing occur. Lastly, subgroup analysis for bacterial and viral pathogens was performed to establish an understanding of potential differences, however, the smaller numbers of patients with a viral pathogen is a limitation and future studies with larger numbers of infants with viral meningitis should be performed to better understand the accuracy of MR imaging.

CONCLUSIONS

MR imaging of the brain demonstrates high specificity and moderate sensitivity for diagnosis of meningitis in infants. The accuracy of MR imaging is greatest when performed within 7 days of the time of presentation, but the specificity remains for a much longer time period. Accuracy does not appear to be affected by pretreatment with antibiotics or acyclovir, prematurity, or neonatal age. Institutional selection bias for imaging may affect the results of the accuracy of MR imaging for diagnosis of meningitis.

Disclosure forms provided by the authors are available with the full text and PDF of this article at www.ajnr.org.

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