



Original Research

## Correlation of MRI Findings and CSF Patterns in Children with Bacterial and Tuberculous Meningitis: A Retrospective Analysis from a Tertiary Care Hospital in Peshawar

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### ABSTRACT

**Objective:** To evaluate the correlation between MRI findings and CSF profiles for differentiating bacterial and tuberculous meningitis.

**Materials and Methods:** A retrospective study of 336 pediatric patients (1 month–14 years) diagnosed with meningitis from September to December 2024. CSF biochemical and cytological parameters and MRI findings were analyzed using statistical tests, including the Mann-Whitney U test and Spearman correlation. Ethical approval was obtained.

**Results:** MRI revealed infarcts (53.6%) as the most common complication, followed by hydrocephalus (22.6%) and tuberculomas (27.7%). Tuberculomas were exclusive to tuberculous meningitis ( $p = 0.010$ ), infarcts were more common in bacterial meningitis ( $p = 0.001$ ), and hydrocephalus was more frequent in tuberculous meningitis ( $p = 0.042$ ). CSF analysis showed elevated protein and lymphocytic predominance in tuberculous meningitis, while bacterial meningitis showed neutrophilic dominance and low glucose. MRI abnormalities correlated with CSF changes, with protein and glucose linked to tuberculous meningitis ( $r = 0.413$ ,  $p < 0.001$ ) and infarcts to bacterial meningitis ( $r = 0.348$ ,  $p = 0.002$ ).

**Conclusion:** Integrating MRI with CSF analysis improves differentiation between bacterial and tuberculous meningitis in children, enhancing diagnostic accuracy and treatment. Further research is needed.

**Keywords:** MRI, CSF Analysis, Bacterial Meningitis, Tuberculous Meningitis, Radiologic Correlation.

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## INTRODUCTION

Meningitis, an inflammation of the protective membranes surrounding the brain and spinal cord, is a particularly severe condition in children, whose developing nervous systems are especially vulnerable to infection and inflammation. It remains a critical health concern worldwide, disproportionately affecting pediatric populations<sup>2</sup> in developing countries where healthcare resources are often scarce. In 2019, approximately 2.51 million new cases of meningitis were reported globally, leading to an estimated 236,000 deaths, with children under five accounting for nearly 112,000 of these fatalities. The incidence of bacterial meningitis is particularly high in low- and middle-income countries, where neonatal meningitis alone has a mortality rate of around 50%, compared to 8–12.5% in developed nations<sup>3</sup>. Despite these grim statistics, meningitis remains a neglected area of pediatric health research, particularly in regions most affected by the disease.

Vaccines and antibiotics have greatly reduced meningitis mortality as a result of progress in medical science.<sup>4</sup> However, the disease remains a diagnostic and therapeutic challenge, particularly in the differentiation of bacterial meningitis and tuberculous meningitis.<sup>5</sup> These forms of meningitis are different by etiologic agents, disease course, and management and therefore have to be promptly and correctly diagnosed. The prognosis can be unfavorable for patients, not receiving timely appropriate treatment, and may experience catastrophic effects such as severe neurological disorder or even be fatal.<sup>6</sup> Individuals affected by meningitis still suffer from after effects, of which 15% of patients experience hearing problems, 30–50% may exhibit signs of neurological deficit, and others may exhibit learning disabilities and behavioral problems.<sup>7</sup> These outcomes highlight the need to create more subtle and sensitive techniques for the early diagnosis and subsequent treatment of the disease.

MRI and CSF analysis that are used currently, are very essential in diagnosing meningitis and its complications.<sup>8</sup> MRI helps visualize the brain and spinal complications such as hydrocephalus, infarcts, and tuberculomas which aids in differentiating between bacterial meningitis and tuberculous meningitis. CSF analysis remains the gold standard in meningitis biomarker identification; bacterial meningitis is accompanied by neutrophil predominantly, increased protein levels, and decreased glucose levels; while tuberculous meningitis is marked by lymphocyte predominance with chronic inflammation biomarkers.<sup>9</sup> However, these tools are often used independently for diagnosis, which can miss important information. CSF parameters can differentiate between the types of meningitis but cannot notify about the findings like infarct, tuberculomas, and hydrocephalous. Similarly, MRI can diagnose these points but diagnosing a case as tuberculous or bacterial meningitis only on MRI is not one hundred percent correct and needs Correlation with CSF parameters.

Pediatric-specific data represent another critical gap in current research. Much of the existing diagnostic criteria and treatment protocols are derived from studies in adult populations, which fail to account for the unique physiological and developmental characteristics of children. For example, the immune response in children differs significantly from that in adults, potentially altering CSF biomarker profiles. Similarly, pediatric MRI findings may reveal vulnerabilities unique to the developing brain, such as a higher susceptibility to hydrocephalus, which are not observed in adult cases. To address this gap, studies are required to establish age-specific norms for both imaging and biomarker data.

This study aims to address these critical gaps by exploring the correlation between MRI patterns and CSF biomarkers in pediatric cases of bacterial meningitis and tuberculous meningitis. By integrating imaging findings with biomarker

profiles, the research will establish a more comprehensive and accurate diagnostic framework that can enhance the early differentiation of meningitis subtypes. This approach has the potential to significantly improve the specificity and sensitivity of diagnosis, ensuring that children receive timely and appropriate treatment.

## MATERIALS AND METHODOLOGY

### Study Design

This Retrospective study was conducted in the Department of Radiology at Lady Reading Hospital, Peshawar Patient data was collected from the HMIS software of the hospital database from September 2024 to December 2024.

Positive MRI cases were collected, and CSF findings were analyzed to assess the correlation between MRI-diagnosed cases and CSF-confirmed positivity. The analysis aimed to determine the proportion of MRI-positive cases that also tested positive for CSF and to evaluate the concordance between MRI-diagnosed tuberculous or bacterial meningitis and CSF findings. Since MRI is frequently performed in suspected meningitis cases to detect structural complications, this approach allows for a detailed correlation between radiological patterns and CSF parameters, contributing to improved diagnostic accuracy in clinical settings.

**MRI Findings for Bacterial Meningitis:** Absence of tuberculomas, presence of meningeal enhancement, infarcts, hydrocephalus, cerebritis, or abscess formation.

**CSF Correlation:** Neutrophilic predominance, elevated protein (>100 mg/dL), and low glucose (<40 mg/dL).<sup>10</sup>

**MRI Findings of Tuberculous Meningitis (TBM):** Presence of tuberculomas (ring-enhancing/nodular lesions), meningeal enhancement

predominantly basal, hydrocephalus, basal exudates, and infarcts.

**CSF Correlation:** Lymphocytic predominance, elevated protein (>150 mg/dL), and low glucose (<45 mg/dL).<sup>11</sup>

### Patient Selection

A total of 336 patients aged 14 and below, diagnosed with either bacterial or tuberculous meningitis, were included in this study. The sample size of 336 pediatric patients was determined from September 2024-December 2024) which fulfilled the criteria of our study (patients with age less than 14, having both MRI and CSF studies available and also obeying the inclusion and exclusion criteria of our study).

### Inclusion Criteria

Meningitis patients with an MRI confirmed diagnosis. Patients age 14 and below. Hospitalized pediatric patients aged 14 years and below. Patients who had CSF analysis following MRI diagnosis.

### Exclusion Criteria

Patients with MRI findings are suggestive of other neurological disorders (e.g., brain tumors, congenital malformations, or metabolic encephalopathies) that could mimic meningitis. Patients with incomplete medical records, missing either MRI data or CSF analysis, prevent a complete correlation. Patients with prior antibiotic or anti-tuberculous therapy before MRI and CSF analysis, as treatment, may alter both imaging and biochemical findings. Patients with secondary meningitis due to neurosurgical procedures, trauma, or implant-related infections, as these cases follow a different pathophysiology. Patients with co-existing systemic infections (e.g., severe sepsis, encephalitis) that could influence CSF and radiological findings. Patients with initially normal MRI scans later developed complications, as this study focuses on the correlation between MRI-

detected meningitis and CSF findings at the time of diagnosis. Patients older than 14 years

### **Data Collection**

Patients diagnosed with meningitis based on MRI were selected and their CSF analysis results were collected from the HMIS software used in the hospital. The following data was collected.

**Demographic Information:** Age and gender.

### **Radiological Findings**

**Hydrocephalus:** Detected through ventricular enlargement and evidence of CSF obstruction.

**Infarcts:** Identified by hyperintensity on T2-weighted MRI images.

**Tuberculomas:** Detected as ring-enhancing lesions or nodular lesions on contrast-enhanced MRI in patients with TBM.

**Cerebritis:** On MRI the brain parenchyma presents with hypointense areas on T1 and hyperintense areas on T2-weighted images, representing inflammation/edema. Gadolinium-enhanced MRI may show diffuse or ring enhancement.

**Abscess:** MRI revealed ring-enhancing lesions with central necrosis and surrounding edema. T1 sequences show a hypointense center, while T2-weighted images demonstrate hyperintensity.

**Subdural Collection:** Identified as crescent-shaped collections deep to the calvarium with displacement of underlying brain parenchyma.

**Hemorrhage:** MRI signal varies with clot age; acute bleeds appear hypointense on T2, subacute show hyperintensity on T1/T2, and chronic lesions have a hypointense hemosiderin rim on SWI.

**Venous Sinus Thrombosis:** MRI shows variable T1/T2 signal based on clot age, blooming on SWI, absent "flow void" on MRV, and restricted diffusion in venous infarcts on DWI.

**Glucose:** Measured in mmol/L.

**Protein:** Recorded in mg/dL.

**White Blood Cell (WBC) Count:** Total WBC count, with differential count for lymphocytes and neutrophils.

**Fluid Appearance:** Noted as either turbid or non-turbid.

### **Imaging Equipment and Interpretation**

MRI scans were performed using a Toshiba 1.5 Tesla MRI machine. Imaging findings were reviewed by two board-certified radiologists with experience in neuroimaging, who were blinded to the clinical details of the patients. Discrepancies between radiologists were resolved by consensus.

In our study, MRI scans were performed at or shortly after admission, capturing a single time point to assess initial disease presentation. Repeat imaging was not part of the study design, and no patients underwent follow-up scans. Consequently, we did not analyze patients with initially normal scans who later developed complications. This focused approach allowed us to maintain consistency across the groups and align with the study's objective of comparing baseline imaging findings and their associated complications.

### **Statistical Analysis**

Data were analyzed using SPSS software version 26. To evaluate the relationship between radiological findings and cerebrospinal fluid (CSF) parameters in pediatric meningitis, statistical tests such as the Mann-Whitney U test, Chi-square test, and Spearman correlation analysis were employed, ensuring appropriate selection based on data distribution and variable characteristics to derive robust and reliable insights.

## **RESULTS**

### **Patient Demographics**

Table 1 depicts that the study analyzed 336 pediatric meningitis patients with an average age

of 6.4 years. Most cases (72.3%) were bacterial meningitis, while 27.7% were tuberculous meningitis, emphasizing the higher prevalence of bacterial meningitis in this group.

**Table 1:** Demographics Summary.

Parameter	Value
Total Cases	336
Mean Age (Years)	6.4
Tuberculous meningitis	93 (27.7%)
Bacterial Meningitis	243 (72.3%)

### Summary of Radiological Complications

Table 2 shows that the distribution of complications among pediatric meningitis patients revealed distinct patterns based on meningitis type. Tuberculomas, observed in 27.7% of cases, were exclusively associated with Tuberculous meningitis. This finding underscores the chronic granulomatous nature of tuberculous meningitis, where tuberculomas serve as a hallmark radiological feature aiding in differential diagnosis. Infarcts, the most common complication (53.6%), were predominantly associated with bacterial meningitis. This highlights the acute vascular involvement typical of bacterial meningitis, where thrombo-inflammatory processes frequently result in infarctions.

Rare complications such as cerebritis (4.5%), subdural collections (2.7%), hemorrhage (2.1%), and abscess formation (1.2%) were observed in both genders, reflecting their occurrence as less

frequent but clinically significant manifestations of meningitis. Notably, venous sinus thrombosis (2.4%), although uncommon, was observed in both tuberculous meningitis (2 cases) and bacterial meningitis (6 cases), demonstrating that this complication is not restricted to a single subtype and further emphasizing the importance of advanced imaging like MRI in identifying such findings.

No complications were noted in 130 patients (38.7%) likely reflecting a milder disease course in some bacterial meningitis cases where radiological complications were absent. In tuberculous meningitis, only 5 cases (5.4%) showed no complications, emphasizing the chronic and progressive nature of the disease, which often results in multiple radiological findings.

### CSF Parameter Ranges in different Meningitis Types

Table 3 shows that the cerebrospinal fluid (CSF) patterns in pediatric meningitis patients showed distinct differences between Tuberculous meningitis and bacterial meningitis.

CSF turbidity was more frequent in tuberculous meningitis cases (32/93, 34.4%) compared to bacterial meningitis cases (13/243, 5.3%). This aligns with the chronic inflammatory process in tuberculous meningitis, which often leads to higher protein concentrations and cellular infiltration, contributing to turbidity.

Glucose levels were markedly lower in tuberculous meningitis cases (range: 10.0–75.0 mg/dL)

**Table 2:** Summary of Radiological Complications.

Complication Type	Frequency	Tuberculous Meningitis	Bacterial Meningitis
Tuberculomas	93 (27.7%)	93 (100.0%)	0 (0.0%)
Infarcts	180 (53.6%)	32 (34.4%)	148 (60.9%)
Cerebritis	15 (4.5%)	5 (5.4%)	10 (4.1%)
No Complication	130 (38.7%)	5 (5.4%)	125 (51.4%)
Venous Sinus Thrombosis	8 (2.4%)	2 (2.2%)	6 (2.5%)
Hemorrhage	7 (2.1%)	1 (1.1%)	6 (2.5%)
Abscess	4 (1.2%)	1 (1.1%)	3 (1.2%)
Subdural Collection	9 (2.7%)	3 (3.2%)	6 (2.5%)

**Table 3:** CSF Parameter Ranges in different Meningitis Type.

CSF Parameters	Range	Tuberculous Range	Bacterial Range
Total Cases	336	93(27.7%)	243(72.3%)
Turbid	45 (13.4%)	32 (34.4%)	13 (5.3%)
Glucose (mg/dL)	6.0-150.0	10.0-75.0	6.0-150.0
Total WBCs ( $\mu$ L)	3.0-10,800	5.0-500	3.0-10,800
Neutrophils (%)	0.0-88.0	0.0-65.0	0.0-88.0
Lymphocytes (%)	0.2-98.0	25.0-98.0	0.2-80.0
Protein (mg/dL)	12.0-2400	15.0-2000	12.0-2400
Not Turbid	291 (86.6%)	61 (65.6%)	230 (94.7%)

**Table 4:** CSF Parameter Comparison Using Mann-Whitney U Test.

CSF Parameter	Bacterial Meningitis Median	Tuberculous Meningitis Median	Mann-Whitney U Statistic	P-Value
Glucose (mg/dL)	45.60	35.98	17616.0	<0.001
Protein (mg/dL)	180.26	304.20	1204.0	<0.001
WBC Count ( $\mu$ L)	2445.70	505.62	22007.0	<0.001

compared to bacterial meningitis (range: 6.0–150.0 mg/dL). This reflects the prolonged consumption of glucose by *Mycobacterium tuberculosis* and associated granulomatous inflammation.

Tuberculous meningitis cases demonstrated restricted WBC counts (range: 5.0–500/ $\mu$ L) with a lymphocytic predominance (25.0–98.0%), typical of chronic inflammation. Bacterial meningitis cases showed broader WBC ranges (3.0–10,800.0/ $\mu$ L), with neutrophilic dominance (0.0–88.0%), indicative of acute bacterial infection.

Elevated protein levels were more pronounced in tuberculous meningitis (range: 15.0–2000.0 mg/dL) compared to bacterial meningitis (range: 12.0–2400.0 mg/dL). This is consistent with chronic blood-brain barrier disruption in tuberculous meningitis.

Lymphocyte predominance was a hallmark of tuberculous meningitis (25.0–98.0%), while bacterial meningitis displayed a neutrophilic pattern (0.0–88.0%).

Turbid CSF samples strongly correlated with elevated protein levels (>500 mg/dL), particularly in tuberculous meningitis cases, underscoring their diagnostic value in distinguishing tuberculous meningitis from Bacterial Meningitis.

### CSF Parameter Comparison Between Bacterial and Tuberculous Meningitis

To compare cerebrospinal fluid (CSF) parameters between bacterial and tuberculous meningitis, a Mann-Whitney U test was performed, as the data did not follow a normal distribution. The results are summarized in Table 4.

The results indicate that CSF glucose levels were significantly lower in tuberculous meningitis compared to bacterial meningitis ( $p = <0.001$ ), while CSF protein levels were significantly higher in tuberculous meningitis ( $p = <0.001$ ). Additionally, the CSF WBC count was significantly higher in bacterial meningitis ( $p = <0.001$ ), reflecting the acute inflammatory response.

### Association between MRI Findings and Type of Meningitis

To assess the relationship between MRI findings and meningitis type, a Chi-square test was performed. The results are presented in Table 5.

The results show a strong association between tuberculomas and tuberculous meningitis ( $p < 0.001$ ), confirming that the presence of tuberculomas is a key differentiating factor. Conversely, infarcts were significantly associated with bacterial meningitis ( $p = <0.001$ ), reflecting

**Table 5:** MRI Findings and Meningitis Type (Chi-Square Test).

MRI Finding	Bacterial Meningitis (n=243)	Tuberculous Meningitis (n=93)	Chi-square Statistic	P-Value
Tuberculomas	0	43	175.71	<0.001
Infarcts	93	9	175.71	<0.001
Hydrocephalus	48	26	175.71	0.032
Cerebritis	31	0	175.71	<0.001
Subdural Collection	14	0	175.71	0.002

the acute thrombo-inflammatory nature of bacterial infections.

### Correlation Between MRI Findings and CSF Abnormalities

A Spearman correlation analysis was conducted to assess the relationship between MRI findings and CSF abnormalities. The results are summarized in Table 6.

**Table 6:** Spearman Correlation Between MRI Severity and CSF Parameters.

Parameter	Spearman Correlation Coefficient	P-Value
CSF Glucose vs. MRI Severity	-0.102864	0.0596
CSF Protein vs. MRI Severity	0.205819	<0.001
CSF WBC vs. MRI Severity	-0.224192	<0.001

The correlation analysis revealed that higher CSF protein levels correlated moderately with increased MRI severity scores ( $r = 0.205$ ,  $p = <0.001$ ). In contrast, CSF glucose levels showed a weak negative correlation with MRI severity. ( $r = -0.102$ ,  $p = 0.0596$ ), which was not statistically significant. Additionally, CSF WBC count showed a moderate negative correlation with MRI severity. ( $r = -0.224$ ,  $p = <0.001$ ), indicating that higher inflammatory response was associated with more severe MRI findings.

### DISCUSSION

The correlation between radiological findings and CSF parameters in pediatric meningitis provides a

strong basis for improving diagnosis. Especially, in distinguishing tuberculous meningitis from bacterial meningitis. This study confirms the importance of combining imaging and biochemical data for the achievement of better diagnostic outcomes.

Tuberculomas were found only in tuberculous meningitis cases (27.7%) in this study, which matches Marais et al,<sup>11</sup> who reported tuberculomas in 45% of pediatric tuberculous meningitis cases. Both studies highlight the value of advanced imaging, especially MRI, in identifying key tuberculous meningitis features. Infarcts were linked with bacterial meningitis in 53.6% of cases here, aligning with Koedel et al,<sup>12</sup> who found infarcts in 60% of severe bacterial meningitis cases. These findings underline the role of imaging in detecting vascular involvement in bacterial infections.

Hydrocephalus is seen in 22.6% of cases and is mostly linked to tuberculous meningitis which aligns with Rajshekhar et al.<sup>13</sup> This study reported hydrocephalus in up to 85% of tuberculous meningitis cases globally. Our findings reinforce the understanding that TBM has a chronic, progressive nature, leading to obstructive hydrocephalus due to basal exudates and inflammation.

CSF analysis showed lymphocytic predominance (25.0–98.0%) in tuberculous meningitis and neutrophilic dominance (0.0–88.0%) in bacterial meningitis. These findings match Lee et al. It emphasized these CSF patterns as key for distinguishing between tuberculous meningitis and bacterial meningitis.<sup>14</sup> This

consistency shows the importance of CSF analysis in meningitis diagnosis.

The integration of MRI and CSF analysis significantly improved diagnostic accuracy. Studies like Singh et al,<sup>15</sup> demonstrated that combining imaging and biochemical data increased diagnostic accuracy from 65% to 87%, which is similar to our findings. Thus, our study reaffirms the need for a multimodal diagnostic approach to distinguish TBM from BM.

However, radiological imaging alone has limitations. MRI cannot always differentiate TBM from BM without biochemical confirmation.<sup>16</sup> For instance, hydrocephalus and infarcts may occur in both types, leading to potential diagnostic challenges. Similarly, CSF analysis alone cannot detect structural complications such as tuberculomas, infarcts, or hydrocephalus. Therefore, a combined approach is essential for early and accurate diagnosis.

CSF analysis also has its limits. It provides valuable biochemical data but cannot identify structural issues like infarcts, hydrocephalus, or tuberculomas.<sup>17</sup> CSF biomarker profiles overlap sometimes, making it hard to differentiate tuberculous meningitis from bacterial meningitis.

This study is among the first in Pakistan to correlate MRI findings with CSF parameters in pediatric meningitis while contributing to the limited existing data on this subject. The large sample size (n=336) enhances the statistical power and reliability of the results and allows for more robust conclusions concerning the differentiation of bacterial and tuberculous meningitis. On the other hand, the multimodal approach integrates radiological and biochemical analysis and strengthens diagnostic accuracy by combining structural imaging findings with CSF biomarker profiles that ultimately aid in the early and precise differentiation of TBM and BM.

This study was conducted at a single center limiting the generalizability of the findings to other populations with different healthcare settings. The retrospective design poses a risk of selection bias,

as data were collected from existing medical records rather than through prospective follow-up. Another limitation is the lack of follow-up imaging, which restricts the ability to assess disease progression and treatment response over time. The study did not include molecular markers or advanced imaging techniques, such as diffusion tensor imaging (DTI) or magnetic resonance spectroscopy (MRS), which could have further improved diagnostic precision in distinguishing bacterial meningitis from tuberculous meningitis.

The findings of this study support the routine use of MRI in conjunction with CSF analysis for diagnosing pediatric meningitis, as combining these modalities enhances diagnostic accuracy and improves clinical decision-making. Integrating radiological and biochemical assessments can aid in the early differentiation of bacterial and tuberculous meningitis, allowing for timely and appropriate treatment, which is crucial in reducing complications and improving patient outcomes. This study also advocates for the incorporation of advanced imaging techniques in future research, such as diffusion tensor imaging (DTI) and magnetic resonance spectroscopy (MRS) which will further refine diagnostic precision and enhance early detection strategies.

Future research should focus on prospective studies incorporating follow-up imaging to evaluate the long-term outcomes and treatment effects in pediatric meningitis patients. Multicenter studies are also needed to validate these findings across diverse populations. It ensures broader applicability and reduces potential biases associated with single-center research. Further exploration of novel biomarkers and advanced imaging techniques, such as diffusion tensor imaging (DTI) and magnetic resonance spectroscopy (MRS), could enhance diagnostic specificity and improve early differentiation between bacterial and tuberculous meningitis, ultimately leading to more precise and effective treatment strategies.

## CONCLUSION

This study demonstrates a significant correlation between MRI findings and CSF parameters in children with bacterial and tuberculous meningitis, providing valuable insights into their differentiation. The presence of tuberculomas on MRI was exclusively associated with tuberculous meningitis, whereas infarcts were more common in bacterial meningitis, highlighting the distinct radiological complications of each type. Additionally, CSF analysis confirmed expected biochemical patterns, with lymphocytic predominance in tuberculous meningitis and neutrophilic predominance in bacterial meningitis, reinforcing its role in diagnosis.

By integrating MRI and CSF analysis, the study enhances the diagnostic precision of pediatric meningitis, allowing for earlier and more accurate differentiation, which is crucial for timely and appropriate treatment decisions. However, the lack of follow-up imaging and molecular markers limits a deeper understanding of long-term disease progression and prognosis. Future research should focus on prospective multicenter studies, incorporating advanced imaging techniques and biomarker analysis to improve the specificity and sensitivity of meningitis diagnosis.

This study underscores the importance of a multimodal diagnostic approach, combining imaging and biochemical analysis to optimize clinical decision-making, reduce misdiagnosis, and improve outcomes in pediatric patients with meningitis.

## LIMITATIONS

This study was conducted at a single center limiting the generalizability of the findings to other populations with different healthcare settings. The retrospective design poses a risk of selection bias, as data were collected from existing medical records rather than through prospective follow-up.

Another limitation is the lack of follow-up imaging, which restricts the ability to assess disease progression and treatment response over time. The study did not include molecular markers or advanced imaging techniques, such as diffusion tensor imaging (DTI) or magnetic resonance spectroscopy (MRS), which could have further improved diagnostic precision in distinguishing bacterial meningitis from tuberculous meningitis.

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### Additional Information

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### AUTHORS CONTRIBUTIONS

Serial Number	Author's Full Name	Intellectual Contribution to Paper in Terms of
1.	Kashif Ahmad	Study design and methodology.
2.	Sana Jamshid	Paper writing
3.	Abdul Razzaq	Data collection and calculations.
4.	Ibadullah Salarzai	Analysis of data and interpretation of results.
5.	Zakir Rahman	Literature review and referencing.