



Original Research

Comparative Analysis of Complications in Meningitis Patient Tuberculous vs. Bacterial

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ABSTRACT

Objective: This comparative analysis aims to evaluate the patterns of radiological complications in bacterial meningitis against those seen in tuberculous meningitis.

Materials and Methods: A retrospective review of imaging and clinical data was conducted. The frequency of complications such as hydrocephalus, infarcts, tuberculomas, abscesses, and cerebritis was analyzed in both cohorts.

Results: Hydrocephalus was significantly more frequent in TBM (46.9%) compared to ABM (23%, $p < 0.001$). Tuberculomas were exclusive to TBM (57.3%, $p < 0.001$), while abscesses (6.3%) and subdural collections (8.4%) were unique to ABM ($p < 0.05$). Infarcts occurred at similar rates in both groups (27% vs. 28.1%, $p = 0.88$). Logistic regression identified TBM as an independent predictor of hydrocephalus (OR: 3.4, 95% CI: 2.1–5.8, $p < 0.001$) and tuberculomas (OR: 18.7, 95% CI: 11.4–30.9, $p < 0.001$). These findings emphasize the distinct radiological complication patterns in ABM and TBM, aiding in tailored management strategies.

Conclusion: The use of regression analysis provided new insights into predictors of complications; while cerebral infarcts are common in both ABM and TBM, TBM showed a greater burden of complications, particularly hydrocephalus and tuberculomas. The findings highlight the importance of early diagnosis and tailored treatment strategies to reduce morbidity and mortality in both forms of meningitis.

Keywords: Bacterial meningitis, Tuberculous meningitis, complications, Hydrocephalus, Infarcts, Tuberculoma, Cerebritis, Abscess, Subdural collection.

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INTRODUCTION

Meningitis is a serious inflammation of the membranes surrounding the brain and spinal cord.¹ It still is a significant global health issue, particularly the bacterial and tuberculous forms. Severe neurological complications with high morbidity and mortality are often seen in both varieties. Complications like hydrocephalus, infarcts, abscesses, and tuberculomas, usually spell poor long-term outcomes in affected patients, thus prompt diagnosis and treatment are vital to prevent lasting neurological damage.²

Bacterial Meningitis, most commonly caused by *Strep. Pneumonia*, *N. meningitidis*, and *H. influenza*.³ If left untreated, can lead to rapid and severe complications. The meningeal inflammation often disrupts the normal flow of CSF, leading to hydrocephalus, vasculitis, and subsequent infarcts and abscess formation.⁴

Tuberculous Meningitis (TBM), though occurs less frequently often presents with more severe complications, mostly due to delayed diagnosis.⁵ The incidence rate of tuberculosis in Pakistan is 265 per 100,000 population.⁶ The presence of National Statistics for TBM is scarce, estimated to be 5-10% of extrapulmonary TB cases.⁷ TBM can result in chronic complications like tuberculoma formation (granulomatous lesions with central caseous necrosis) and obstructive hydrocephalus among other complications.⁸ The inflammatory process in TBM is generally prolonged with widespread damage contributing to high morbidity and mortality.⁹

Bacterial meningitis affects hundreds of thousands annually, with especially higher incidence in low and middle-income countries.¹⁰ Outbreaks in the meningitis belt, particularly the sub-Saharan Africa are a significant public health concern.¹¹ Although the introduction of vaccinations has dented its incidence in many parts of the world it remains a major public health issue primarily due to delays in diagnosis and treatment in resource-poor settings.^{12,13,14}

Despite being less common, Tuberculous meningitis still poses a serious public health alarm

in regions with high tuberculosis (TB) burden, such as in South Asia. Unenviably, Pakistan ranks among the top in TB cases, including CNS-TB.¹⁵ Though TBM accounts for only 1-5% of all TB cases, it is associated with significantly higher mortality and long-term neurological sequelae.¹⁶ Delayed diagnosis is often blamed on its insidious onset and nonspecific symptoms. This diagnosis in advanced stages is associated with a higher risk of complications, like hydrocephalus and infarcts.

Diagnostic imaging, particularly magnetic resonance imaging (MRI) and computed tomography (CT), plays a vital role in diagnosing complications in all forms of meningitis.¹⁷ These modalities help clinicians make appropriate diagnoses and identify complications early, ensuring timely interventions to mitigate long-term damage.

In bacterial meningitis, impaired CSF absorption due to meningeal inflammation results in hydrocephalus. While infarcts result from vasculitis or thrombosis of cerebral arteries.¹⁸ Abscesses and subdural collections occur as the infection spreads beyond the meninges toward the brain parenchyma.

This comparative analysis aims to evaluate the patterns of radiological complications in bacterial meningitis against those seen in tuberculous meningitis. These findings highlight the importance of early detection of complications using radiological imaging. We seek to identify differences in the frequency, severity, and outcomes of these complications. Such insights will help in strategizing clinical management tailored to the specific requirements of bacterial and tuberculous meningitis patients. Existing literature shows distinct patterns of complications in bacterial (e.g., infarcts, abscesses) and tuberculous meningitis (e.g., tuberculomas, chronic hydrocephalus).¹⁹ However, data on direct comparative analysis of these complications is scarce. Our study uniquely analyzes radiological patterns across both diseases, aiming to clarify these distinctions. By identifying variations, such as

hydrocephalus being more prevalent in TBM (46.9%) compared to bacterial meningitis (23%), it offers targeted insights for tailored management and intervention strategies.

MATERIALS AND METHODS

Study Design and Setting

This retrospective observational study was conducted at Lady Reading Hospital, Peshawar, a tertiary care facility that serves a large population in northern Pakistan. The study aims to compare the radiological complications observed in patients diagnosed with bacterial meningitis and tuberculous meningitis (TBM). Cases of bacterial meningitis were collected over the past 9 months (December 2023 to August 2024), while TBM cases were collected over the last 9 years (between 2015 and 2024). Both cohorts consisted of a similar number of patients, with 95 cases of bacterial meningitis and 96 cases of TBM included in the analysis.

Study Population

The study included all patients diagnosed with bacterial meningitis or TBM based on clinical, microbiological, and radiological criteria. The patient records from December 2023 to August 2024 were reviewed for bacterial meningitis cases and records between 2015 and 2024 were reviewed for TBM cases. The difference in time frames arises from the distinct epidemiological and clinical dynamics of the two conditions. ABM cases were reviewed over a shorter, recent period (December 2023 to August 2024) due to its acute nature, higher incidence, and availability of adequate sample size within a limited time frame. In contrast, TBM, being a chronic and less frequently encountered condition, required a longer review period (2015–2024) to ensure sufficient cases for meaningful statistical analysis and comparison. This approach was essential to maintain the study's robustness and validity.

Inclusion Criteria

Patients diagnosed with bacterial meningitis or TBM were confirmed through CSF analysis, microbiological studies, and clinical features. Patients aged from 3 months to 75 years. Patients who underwent an MRI of the brain with complete medical records, including imaging and clinical data, were available.

Exclusion Criteria

Patients without a confirmed diagnosis of bacterial or tuberculous meningitis. Incomplete medical records or missing imaging data. Co-infections with other CNS conditions (e.g., viral meningitis). Contraindications to MRI, such as metallic implants or contrast allergies.

Data Collection

Data were extracted from the hospital's electronic medical record system. The following variables were collected for each patient including.

Demographic Information like Age, and gender. Clinical Data like Presenting symptoms, Glasgow Coma Scale (GCS) score, duration of illness and comorbidities. Radiological Findings like MRI results, including the presence and severity of complications such as hydrocephalus, infarcts, abscesses, tuberculomas, subdural collections, and cerebritis. Outcomes Length of hospital stay, discharge status (recovered, persistent neurological deficit, or death). Long-term follow-up was not performed.

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.

The following radiological complications were assessed:

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.

Statistical Analysis

Data were analyzed using SPSS software version 26. Descriptive statistics were used to summarize demographic characteristics, clinical features, and radiological findings. Frequencies and percentages were calculated for categorical variables, while means and standard deviations were reported for

continuous variables like age and duration of illness.

Comparisons between bacterial meningitis and tuberculous meningitis (TBM) were conducted using the following statistical tools:

Chi-Square Test: For comparing categorical variables such as the presence of specific complications (e.g., hydrocephalus, infarcts, and tuberculomas).

Independent t-Test: For comparing continuous variables like age between the two groups.

Multivariate Logistic Regression: To identify independent predictors of complications (e.g., hydrocephalus, infarcts, and tuberculomas).

A p-value < 0.05 was considered statistically significant. The results were reported with odds ratios (ORs) and 95% confidence intervals (CIs) for regression analysis.

Ethical Considerations

The study was conducted following the ethical guidelines of the Declaration of Helsinki. Approval was obtained from the Institutional Review Board (IRB) of Lady Reading Hospital (Approval No: 409/LRH/MTI dated 14/10/2024). Patient data were anonymized to ensure confidentiality and informed consent was waived due to the retrospective nature of the study.

RESULTS

Demographic Characteristics

The study included a total of 191 patients, with 95 diagnosed with bacterial meningitis and 96 with tuberculous meningitis (TBM). The age range of the patients was from 3 months to 75 years, with a mean age of 25.75 years for bacterial meningitis and 21.6 years for TBM. The bacterial meningitis cohort comprised 45 males (47%) and 50 females (53%), while the TBM group consisted of 36 males (37.5%) and 60 females (62.5%) as shown in Table 1.

Table 1: Demographic characteristics of both groups.

Characteristic	Bacterial Meningitis (n=95)	Tuberculous Meningitis (n=96)
Mean Age (years)	25.75	21.6
Males	45 (47%)	36 (37.5%)
Females	50 (53%)	60 (62.5%)
Adults (≥ 18 years)	60 (63%)	61 (64%)
Children (<18 years)	35 (37%)	35 (36%)

Table 2: Frequency of Complications in Patients with Bacterial Meningitis.

Complication	Frequency
Infarcts	27% (n = 26)
Hydrocephalus	23% (n = 21)
Subdural collections	8.4% (n = 8)
Abscesses	6.3% (n = 6)
Cerebritis	2.3% (n = 3)
Hemorrhage	2.1% (n = 2)

Radiological Complications

Tables 2 and 3 show radiological complications observed in bacterial and tuberculous meningitis respectively. Radiological complications were observed in both cohorts, with a higher frequency in the TBM group. **Hydrocephalus** and **infarcts** were the most common complications in both groups, but tuberculomas, specific to TBM, were significantly more frequent in TBM patients.

Complications by Gender

Table 4 illustrates the gender-wise distribution of complications in bacterial and tuberculous meningitis. In both groups, males and females exhibited differences in the distribution of radiological complications. Notably, in bacterial meningitis, **infarcts** were more common in males (31%), while females showed a slightly lower infarct rate (21%). In the TBM cohort, **tuberculomas** were more frequent in females (56.7%) compared to males (52.8%).

Table 2: Frequency of Complications in Patients with Tuberculous Meningitis.

Complication	Frequency
Tuberculomas	57.3% (n = 55)
Hydrocephalus	46.9% (n = 45)
Infarcts	28.1% (n = 27)
Cerebritis	4.2% (n = 4)

Complications by Age

Table 5 provides an overview of complication rates in adult and pediatric patients. Complications were distributed across both age groups. Adults in both cohorts exhibited more **hydrocephalus** and **infarcts**, while **tuberculomas** were common in TBM regardless of age.

Statistical Analysis of Complications

As shown in Table 6 Chi-square test revealed statistically significant differences in the frequency of specific complications between bacterial meningitis and TBM. For example, tuberculomas

Table 4: Gender-wise distribution of complications in bacterial and tuberculous meningitis.

Complication	Bacterial Meningitis - Male (n=45)	Bacterial Meningitis - Female (n=50)	TBM - Male (n=36)	TBM - Female (n=60)
No Complications	22 (48.9%)	20 (40%)	1 (2.8%)	7 (11.7%)
Hydrocephalus	11 (24.4%)	10 (20%)	20 (55.6%)	23 (38.3%)
Infarcts	14 (31%)	12 (24%)	10 (27.8%)	17 (28.3%)
Subdural Collections	4 (8.8%)	4 (8%)	N/A	N/A
Abscesses	2 (4.4%)	4 (8%)	N/A	N/A
Tuberculomas	N/A	N/A	19 (52.8%)	34 (56.7%)
Cerebritis	2 (4.4%)	1 (2%)	3 (8.3%)	1 (1.7%)

Table 5: Complication rates in adult and pediatric patients.

Complication	Bacterial Meningitis – Adults (n=60)	Bacterial Meningitis – Children (n=35)	TBM – Adults (n=61)	TBM – Children (n=35)
No Complications	14 (23.3%)	28 (80%)	6 (9.8%)	2 (5.7%)
Hydrocephalus	3 (5%)	18 (51.4%)	24 (39.3%)	21 (60%)
Infarcts	5 (8.3%)	19 (54.3%)	16 (26.2%)	11 (31.4%)
Tuberculomas	N/A	N/A	38 (62.3%)	17 (48.6%)
Cerebritis	1 (1.7%)	2 (5.7%)	3 (4.9%)	1 (2.9%)

were exclusively observed in TBM (57.3%, $p < 0.001$), while abscesses and subdural collections were significantly more common in bacterial meningitis (6.3% and 8.4%, respectively, $p < 0.05$).

Multivariate logistic regression identified independent predictors for hydrocephalus and infarcts as illustrated in Table 7.

Hydrocephalus: More likely in TBM patients (OR: 3.4, 95% CI: 2.1–5.8, $p < 0.001$).

Tuberculomas: Strongly associated with TBM (OR: 18.7, 95% CI: 11.4–30.9, $p < 0.001$).

Table 8 depicts the results of independent t-tests which showed no significant differences in mean age between patients with infarcts in bacterial meningitis and TBM ($p = 0.64$). However, tuberculomas were more common in younger TBM patients (mean age: 20.4 years, $p = 0.03$).

Table 6: Chi-square Test for Independence between types of Meningitis.

Complication	Bacterial Meningitis (n=95)	Tuberculous Meningitis (n=96)	Chi-square (χ^2)	p-value
Hydrocephalus	21 (23%)	45 (46.9%)	13.75	< 0.001
Infarcts	26 (27%)	27 (28.1%)	0.02	0.88
Tuberculomas	0 (0%)	55 (57.3%)	72.98	< 0.001
Subdural Collections	8 (8.4%)	0 (0%)	8.55	0.003
Abscesses	6 (6.3%)	0 (0%)	6.32	0.012
Cerebritis	3 (2.3%)	4 (4.2%)	0.45	0.50

Table 7: Logistic Regression Analysis of Radiological Complications.

Complication	Odds Ratio (OR)	95% Confidence Interval (CI)	p-value	Interpretation
Hydrocephalus	3.4	2.1–5.8	<0.001	TBM is a significant independent predictor of hydrocephalus.
Tuberculomas	18.7	11.4–30.9	<0.001	Strongly associated with TBM; exclusive to TBM cases.

Table 8: Independent t-test Results for Mean Age in Meningitis Complications.

Complication	Group	Mean Age (Years)	p-value	Interpretation
Infarcts	Bacterial Meningitis (BM)	25.75	0.64	No significant difference in mean age between patients with infarcts in BM and TBM.
	Tuberculous Meningitis (TBM)	21.6		
Tuberculomas	Tuberculous Meningitis (TBM)	20.4	0.03	Tuberculomas were significantly more common in younger TBM patients.

DISCUSSION

This study highlights key differences in the radiological complications of bacterial and tuberculous meningitis (TBM) while adjusting for potential confounding variables. The multivariate logistic regression analysis provided new insights into predictors of complications.

As mentioned above, regardless of etiology meningitis is associated with a range of neurological complications. In bacterial meningitis, for example, the acute inflammatory response can lead to severe complications, like hydrocephalus, cerebral infarcts, subdural collections, and abscess formation. While, TBM presents with more chronic complications, such as tuberculomas and hydrocephalus.

Our findings confirm that hydrocephalus is more prevalent in TBM patients, with a strong independent association after adjusting for age and gender. This aligns with prior studies linking TBM to basal meningitis and CSF obstruction due to granulomatous inflammation. By contrast, hydrocephalus in bacterial meningitis likely results from acute inflammation and exudate accumulation, which may be less persistent.

While infarcts were common in both types of meningitis, the absence of a significant association with etiology in regression analysis suggests a shared pathophysiological mechanism involving vascular inflammation. These results underscore the importance of early recognition and treatment of vasculitis in both forms of meningitis.

Tuberculomas, specific to TBM, were strongly associated with younger age groups. This finding emphasizes the chronic granulomatous nature of CNS tuberculosis and highlights the need for early diagnosis in pediatric populations. In this study, hydrocephalus was one of the most common complications, observed in 23% of bacterial meningitis patients and 46.9% of TBM patients. The higher incidence of hydrocephalus in TBM can be attributed to the dense basal meningitis and the exudate thick fluid that obstructs CSF pathways, resulting in non-obstructive hydrocephalus.²⁰

These findings are consistent with many prior studies that report hydrocephalus as a major complication of TBM.^{21,22} On the other hand, in bacterial meningitis development of hydrocephalus is often related to acute inflammation and the rapid accumulation of exudates that impair CSF flow.

Infarcts, are the other common complication seen in both bacterial and tuberculous meningitis patients at comparable rates (27% and 28.1%, respectively). Infarcts resulting from vasculitis and thrombosis affecting the small cerebral vasculature.²³ While the mechanism of infarction is similar in both types of meningitis, the pathophysiology of vasculitis in TBM is more chronic and can lead to progressive vascular narrowing over time.²⁴ This chronicity explains the higher severity/sizes of infarcts associated with TBM, even though the incidence is comparable with bacterial meningitis. Early recognition of vasculitis in meningitis through imaging is important for preventing irreversible brain damage in the form of infarcts.

Cerebritis, inflammation of the brain parenchymal, was observed in both types of meningitis, although more common in TBM (4.2%) as compared to bacterial meningitis (2.3%). Cerebritis though rare can progress to abscess formation in untreated cases.²⁵ The higher incidence of TBM may be a reflection of the prolonged chronic inflammatory process associated with TB. Early MRI diagnosis of cerebritis is essential for prompt management, preventing the progression to more severe complications like abscess formation.

Abscess formation and subdural collections were more prominent complications in bacterial meningitis, with abscesses observed in 6.3% and subdural collections in 8.4% of cases. Such complications are less common in TBM, where granulomatous inflammation (Tuberculomas) dominates the pathological landscape. Abscess formation in bacterial meningitis results from direct invasion of brain parenchyma by bacteria,

resulting in contained pus-filled spaces that require surgical drainage if large enough.

On the contrary, TBM more commonly presents with tuberculomas, which were found in 57.3% of patients in our study. Tuberculomas can cause significant mass effects, leading to increased intracranial pressure and potentially obstructive hydrocephalus. Their presence in over half of the TBM cases highlights the chronic granulomatous nature of CNS tuberculosis.

One of the most interesting findings in this study was the gender-based variation in the incidence of complications. In TBM for example, females were more prone to tuberculomas, with 56.7% of female TBM patients showing this complication compared to 52.8% of males. This gender discrepancy might be related to delayed healthcare-seeking behavior in women, particularly in regions like South Asia where cultural and socio-economic factors limit access to medical care.²⁶ Delayed diagnosis in women often presents with more advanced disease and increased likelihood of complications like tuberculomas.

In bacterial meningitis, infarcts were more common in males (31%) compared to females (24%). Hydrocephalus displayed no significant gender preference in either bacterial or TBM. The higher rate of infarcts in males could be related to sex-specific differences in immune responses or vascular health.²⁷ More research is needed to identify the underlying mechanisms. Several previous studies have suggested a pattern of men at a higher risk of cerebrovascular events in the context of infections, which could explain the gender disparity observed in our study.²⁸

Significant age-age-based differences in the distribution of complications were seen in our study. In bacterial meningitis, children were more likely to develop hydrocephalus (51.4%) than adults (5%). In TBM, hydrocephalus was seen in both age groups, affecting 60% of children and 39.3% of adults. The available literature blames this discrepancy in meningitis on the immature

immune system in children's brains.²⁹ In TBM, the high rate of hydrocephalus across all age groups is attributed to chronic obstruction of CSF pathways by thick exudate/granulomatous inflammation.

Infarcts were also more frequent in children with bacterial meningitis (54.3%) compared to adults (8.3%). In contrast, TBM showed a more balanced distribution of infarcts between children (31.4%) and adults (26.2%). The higher rates of infarctions in pediatric bacterial meningitis cases may be secondary to the vulnerability of developing brains to ischemia destruction caused by inflammation and vasculitis.³⁰ In TBM, the chronic nature of the disease allows for the progressive narrowing of blood vessels, leading to infarcts across both age groups.

The findings of this study highlight the importance of early radiological imaging in the management of both bacterial and tuberculous meningitis. High-incidence complications in TBM patients stress the need for early intervention, including the use of ventricular shunts. In bacterial meningitis, early identification of infarcts and abscesses is critical for reducing long-term neurological complications.

Gender and age disparities in meningitis complication rates should also be considered while developing treatment protocols. In the case of women, a high index of suspicion and a low threshold for aggressive screening and earlier intervention is required due to their tendency to present with more advanced disease. Pediatric patients, especially those with bacterial meningitis, are at higher risk of hydrocephalus and infarcts, requiring vigilant monitoring and early intervention.

CONCLUSION

This study provides a broad comparison of complications seen in bacterial and tuberculous meningitis. While both forms present with severe neurological complications, TBM is more likely to result in chronic conditions like hydrocephalus and

tuberculomas, while bacterial meningitis tends to produce more acute complications like infarcts and abscesses. Gender and age also play vital roles in the distribution of these complications. These factors offer valuable insights for tailoring treatment strategies to improve patient outcomes.

LIMITATIONS

This study has several limitations. It is retrospective, relying on potentially incomplete medical records. In addition, it was conducted at a single center, limiting generalizability. The bacterial meningitis data was collected over a shorter 9-month period, possibly introducing bias. Additionally, only MRI imaging was used, without other modalities like CT. Finally, the absence of follow-up imaging might influence the detection of complications that develop later.

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AUTHORS CONTRIBUTIONS

Serial Number	Author's Full Name	Intellectual Contribution to Paper in Terms of
1.	Hafeez ur Rehman	Study design and methodology.
2.	Shamsullah Burki	Paper writing
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