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PREDICTORS AND PREVENTION OF NEUROLOGICAL DISABILITY IN ADULT BACTERIAL MENINGITIS: A NARRATIVE REVIEW WITH CLINICAL PERSPECTIVE

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ABSTRACT

Background and objective:

Bacterial meningitis remains a neurological emergency in adults, with substantial mortality and long-term sequelae, including cognitive impairment, hearing loss, seizures, and focal deficits. The objective of this narrative review was to summarize current evidence on predictors of neurological disability and highlight strategies for prevention and long-term care.

Methods:

A narrative literature review was conducted using PubMed, Scopus, and Google Scholar for English-language studies published between 2000 and 2025. Keywords included bacterial meningitis, neurological sequelae, predictors, and adults. A total of 40 studies were included after screening 200 abstracts . Key prospective studies, clinical trials, and reviews were prioritized, and additional references were identified from bibliographies of relevant articles and guidelines.

Results:

Clinical predictors of poor neurological outcome include advanced age, low Glasgow Coma Scale score, seizures at presentation, and delayed antibiotic initiation. Laboratory predictors include low CSF glucose and elevated CSF protein. Radiological findings such as infarcts, hydrocephalus, and ventriculitis are associated with long-term disability. Among pathogens, Streptococcus pneumoniae carries the highest risk of neurological sequelae. Preventive strategies with documented benefit include timely antibiotic therapy, adjunctive corticosteroids, vaccination programs, structured neurorehabilitation, and ongoing follow-up.

Conclusion:

Early recognition of clinical, laboratory, and radiological prognostic indicators can reduce neurological disability in adults with bacterial meningitis. Future priorities should focus on validating biomarkers, establishing longitudinal registries, and exploring artificial intelligence based risk stratification to guide personalized care.

Keywords: Bacterial meningitis; Neurological sequelae; Predictors; Prevention; Adults; Cognitive impairment; Vaccination.

INTRODUCTION

Bacterial meningitis remains a life-threatening neurological emergency in adults, with significant morbidity and mortality worldwide. Despite advances in antimicrobial therapy and supportive care, those who survive frequently experience long-term neurological sequelae, including cognitive impairment, focal deficits, seizures, hearing loss, and reduced quality of life.[1-3.] Streptococcus pneumoniae is the predominant pathogen in adults and is associated with the highest risk of severe complications, while Listeria monocytogenes and Neisseria meningitidis also contribute to morbidity with varying patterns.[4]

Neurological damage in bacterial meningitis is multifactorial, resulting from a combination of direct pathogen effects, intense inflammatory host response, cerebral edema, vasculopathy, infarction, and disturbances in cerebrospinal fluid (CSF) dynamics.[5,6] Understanding these mechanisms is important for

identifying patients at risk of long-term disability.

Several clinical, laboratory, and imaging factors predict adverse outcomes in adult bacterial meningitis. Clinically older age, low GCS, and seizures at presentation are associated with poor prognosis. Laboratory parameters such as low CSF glucose and high CSF protein, along with imaging abnormalities including cerebral infarctions, hydrocephalus, and subdural empyema, further identify high risk patients.

Early recognition of these predictors allows for risk stratification and timely interventions to reduce long-term neurological deficits.[7] Timely empirical antibiotic therapy, adjunctive corticosteroids, and intensive neurocritical care are evidence-based strategies that mitigate neurological injury.[8,9] Public health measures, particularly pneumococcal and meningococcal vaccination, play a critical role in reducing the incidence and severity of adult bacterial meningitis.[10]

Despite multiple studies, few recent reviews focus exclusively on adult populations and systematically summarize predictors of neurological disability, integrating clinical, laboratory, and imaging factors. This review addresses this gap by highlighting current evidence on risk factors for poor outcomes and discussing practical strategies to prevent long-term complications in adults.

METHODS

A non-systematic literature search was conducted in PubMed and Scopus for studies published between January 2000 and April 2025. Google Scholar was used only as a supplementary source to identify additional relevant citations from reference lists, recognizing that it cannot be searched systematically.
Search terms included combinations of: “bacterial meningitis” “neurological sequelae,” “neurological disability,” “predictors,” “outcomes,” “prognosis,” “complications,” “prevention,” “adults,” and “long-term outcomes.” Boolean operators were applied where appropriate (e.g., bacterial meningitis AND neurological sequelae; bacterial meningitis AND predictors). A total of 40 studies were included after screening 200 abstracts.

Because this was a narrative rather than a systematic review, no formal screening protocol, PRISMA flow diagram, or structured inclusion/exclusion pathway was applied. Instead, studies were selected based on their relevance to the review objectives, with preference given to adult-focused research, major guidelines, systematic reviews, and high-quality observational studies addressing predictors of poor outcomes or strategies to prevent neurological complications. No formal quality assessment tools were used, which is consistent with narrative review methodology.

REVIEW AND DISCUSSION

Burden and Pattern of Neurological Sequelae in Adults

Neurological sequelae remain a major source of long-term disability among adults surviving bacterial meningitis. Recent studies report that 25–40% of adult survivors experience persistent deficits, with considerable heterogeneity across populations. Unlike older literature which emphasized mortality, contemporary adult studies highlight morbidity as a major determinant of functional outcome and quality of life.[11-13]

Focal Neurological Deficits

Across modern adult cohorts, focal deficits occur in approximately 15–25% of survivors. These typically result from ischemic infarctions, vasculitis, or cytotoxic edema. Studies consistently show a stronger association with pneumococcal meningitis and delayed antibiotic initiation. Variation in reported prevalence is largely attributable to differences in imaging protocols and timing of assessment.[12]

Hearing Loss

Sensorineural hearing loss remains one of the most studied sequelae. Contemporary adult-only evidence suggests rates of 15–30%, though earlier studies reported higher figures. Pneumococcal infection carries the greatest risk. The strength of evidence is moderate, as newer studies employ audiological follow-up, whereas older studies relied on bedside screening.[7,14]

Cognitive Impairment

Cognitive outcomes vary widely across studies, with rates ranging from 20–40% depending on the timing and method of neuropsychological assessment. Executive dysfunction and memory impairment remain the most common. Evidence quality is limited by heterogeneous tools, inconsistent follow-up intervals, and underreporting in lower-resource settings.[7]

Seizures and Epilepsy

Acute symptomatic seizures occur in 10–30% of adults; however, chronic epilepsy develops in 5–10%, predominantly in those with cortical infarction or parenchymal inflammation. Evidence is strong, given consistent associations demonstrated across imaging-correlated cohort studies.[15]

Hydrocephalus and Intracranial Hypertension

Hydrocephalus is less common in adults populations than in children and neonates, with a prevalence of 5–10% in recent cohorts. When present, it is an important predictor of prolonged hospitalization and poor neurocognitive recovery. Evidence remains limited due to small sample sizes and uneven neuroimaging access in low-resource settings.[16]

Neuropsychiatric Sequelae

Mood and anxiety disorders are increasingly recognized, although few adult-specific studies exist. Reported prevalence ranges from 10–25%, but methodological challenges such as underdiagnosis and short follow-up weaken the strength of evidence.[1]

Predictors of Neurological Sequelae in Adults

Clinical Predictors:

Across reviews and multicenter adult studies the following predictors demonstrate the strongest and most consistent association with neurological sequelae:

- Low Glasgow Coma Scale (GCS) on admission is one of the strongest predictors of adverse outcomes, reflecting the severity of central nervous system (CNS) involvement at presentation.[12]
- Delayed antibiotic therapy , especially beyond 2–3 hours after hospital presentation, increases the risk of neurological complications infarction, hearing loss, epilepsy and mortality.[8,17]
- Acute seizures and focal deficits such as cranial nerve palsies, hemiparesis, or seizures during the acute phase are associated with long-term sequelae like epilepsy and motor deficits.[1,12]
- Advanced age and comorbidities (HIV, alcoholism, diabetes) are associated with increased susceptibility and poorer recovery.[17]

These predictors have high-quality evidence due to reproducibility across multiple contemporary adult cohorts, though few studies adjust completely for confounders like pre-existing cognitive decline.

Laboratory Markers

Recent adult studies identify following laboratory predictors:

- Cerebrospinal fluid (CSF) glucose levels below 1.9 mmol/L and protein concentrations above 2 g/L are indicative of severe inflammation and have been associated with poor outcomes in bacterial meningitis.18 Similarly elevated peripheral white blood cell (WBC) count and a high neutrophil-to-lymphocyte ratio (NLR) at the time of admission have been proposed as predictors of adverse neurological outcomes.19Positive blood cultures, particularly with Streptococcus pneumoniae, are associated with more severe disease and poorer neurological outcomes.[20]

Laboratory predictors show moderate-quality evidence due to heterogeneity in timing of lumbar puncture and varied cut-offs across studies.

Radiological Predictors:

Cerebral infarction, hydrocephalus, brain edema, and ventriculitis on CT/MRI during the acute phase strongly predict persistent deficits like cognitive impairment, seizures, or motor dysfunction MRI-based diffusion abnormalities best predict long-term cognitive dysfunction and post-meningitis epilepsy.[16,21]

Imaging evidence is strong but may be biased toward high-resource settings that routinely use MRI.

Etiological Predictors:

Pneumococcal meningitis causes the highest rate of neurological sequelae, followed by Listeria monocytogenes, while Neisseria meningitidis generally results in fewer long-term deficits.[3]

Linking these predictors to prevention is important for better outcomes in adult bacterial meningitis. For example, a low Glasgow Coma Scale (GCS) score at admission and delays in initiating antibiotic therapy are among the strongest predictors of poor neurological

outcome; therefore, early ICU triage, rapid diagnostic evaluation, and immediate empirical antimicrobial coverage become important preventive steps. Similarly, predictors such as seizures, hydrocephalus, and radiological evidence of infarction also highlight the need for careful neurological monitoring, early neuroimaging, and timely neurosurgical consultation. Identifying these prognostic markers allow the clinicians to translate risk stratification into targeted interventions that can reduce long-term neurological disability.

The conceptual framework is represented in Figure 1.

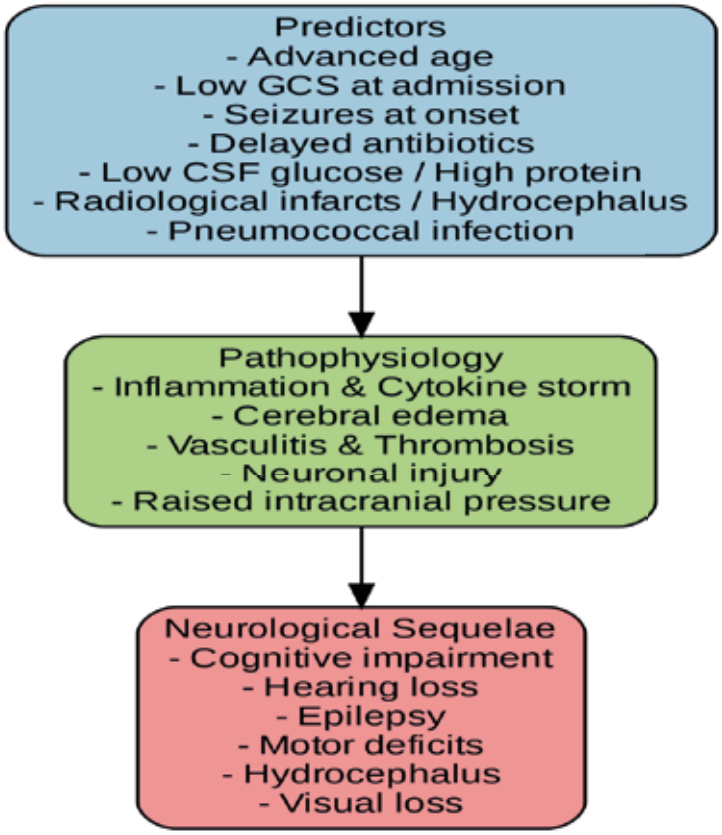

Figure 1: Showing conceptual framework, Predictors →Pathophysiology→ Neurological Sequelae. This pathway links key predictors of poor outcome to long-term neurological sequelae Clinical parameters such as low GCS, seizures, laboratory (low CSF glucose, high protein), radiological (infarcts, hydrocephalus), and microbiological (S. pneumoniae,) factors contribute to pathophysiological changes such as inflammation, cytokine storm, vasculitis, and brain edema, which in turn lead to long-term neurological outcomes including cognitive impairment, hearing loss, and focal deficits. Arrows above indicate the direction of causality.

Abbreviations: GCS = Glasgow Coma Scale; CSF = cerebrospinal fluid.

This conceptual flow demonstrates how early predictors align with later disability and provides a mechanistic basis for risk stratification.

Impact on Quality of Life and Societal Burden

Functional Disability and Daily Living:

Neurological sequelae remain common among adult survivors of bacterial meningitis and are a major source of long-term disability. The most frequently reported deficits include sensorineural hearing loss, cognitive impairment, motor deficits, ataxia, and chronic epilepsy. Contemporary adult cohort data show that 30–50% of survivors experience persistent functional limitations affecting activities of daily living (ADLs), vocational functioning, and social participation.[13,22] Cognitive problems particularly deficits in attention, working memory, and executive function—are strongly associated with poor reintegration into work and reduced overall quality of life in adults.[12]

Psychosocial and Mental Health Impact:
Depression, anxiety, and post-traumatic stress disorder (PTSD) are frequently found in patients of meningitis who survived, particularly among those who experienced ICU admission or had prolonged recovery periods.[23] A population-based study in the Netherlands found that over 25% of adult survivors reported clinically significant psychological distress one year after discharge. Social withdrawal, stigma, and dependency further diminish the overall quality of life.[1]

Healthcare Utilization and Economic Costs:
Post-meningitis disability imposes a substantial economic burden on both individuals and health systems. Adult survivors often require long-term neurologic follow-up, audiology services, rehabilitation, anticonvulsant therapy, and psychiatric care, leading to high direct healthcare costs.[24] While data from Pakistan are limited, the WHO reports that countries with limited health budgets face disproportionately high economic loss because survivors rely more heavily on family caregiving and have reduced access to rehabilitation services.[23]

Caregiver and Societal Burden:
Long-term deficits also affect families and communities. Caregivers experience emotional stress, financial strain, and decreased workforce participation. In LMIC settings, including South Asia, the burden is amplified due to fewer social support systems and limited availability of structured rehabilitation programs.[25] At a societal level, bacterial meningitis in adults leads to significant loss of productive life-years, especially since many patients are young, economically active individuals at the time of illness.[26]

Management and Preventive Strategies:
Mitigating long-term neurological sequelae in adult bacterial meningitis requires a multifaceted approach encompassing early recognition, timely treatment, prevention, and structured follow-up. Evidence suggests that coordinated interventions can reduce neurological morbidity and improve functional outcomes.

Early Diagnosis and Prompt Antimicrobial Therapy:
Early diagnosis and immediate initiation of appropriate empirical antibiotic therapy are critical in minimizing neurological injury and reducing mortality.[20] While some pediatric scoring systems, such as the Bacterial Meningitis Score (BMS), facilitate early diagnosis in children, they are not validated in adults and should not be generalized beyond their intended population.[3] In adult settings, rapid bedside assessment and clinical vigilance remain essential, particularly in resource-limited environments.

Adjunctive Corticosteroids:
Adjunctive dexamethasone reduces the risk of hearing loss and unfavorable outcomes in pneumococcal meningitis when administered before or with the first antibiotic dose.[27,28] However, its efficacy in low- and middle-income countries remains uncertain, with some studies reporting limited benefit due to differences in timing, pathogen distribution, and healthcare infrastructure. Clinicians should consider local epidemiology and resource availability when deciding on corticosteroid use.

Vaccination and Primary Prevention:
Vaccination against Streptococcus pneumoniae, Neisseria meningitidis, and Haemophilus influenzae type b has substantially reduced adult disease incidence in countries with high coverage.[29,30] Booster campaigns and catch-up vaccinations in adults, especially in high-risk groups (e.g., splenectomized individuals, immunocompromised patients), are essential to maintain herd immunity.

Neurorehabilitation and Long-Term Follow-up:
Patients recovering from meningitis require multidisciplinary rehabilitation, including physical therapy, cognitive rehabilitation, audiological support like hearing aids, cochlear implants, and psychological counseling. Regular follow-up is necessary to detect late onset complications, such as post-meningitic hydrocephalus or seizure disorders.[31]

Public Awareness and Health System Preparedness:
Community education about the early symptoms of meningitis and the need for ugent care is important. At the same time, hospitals must be equipped with standardized protocols for the early recognition and management of suspected meningitis, including ready access to lumbar puncture, neuroimaging, and laboratory diagnostics.
Evidence-based management algorithm for suspected bacterial meningitis

Figure 2 presents an evidence-based algorithm for the management of patients with suspected bacterial

meningitis. It highlights initial clinical assessment, identification of high-risk features such as raised ICP, immunosuppression, and altered mental status, and subsequent diagnostic and therapeutic steps. The algorithm is designed to support timely decision making and optimize patient outcomes.

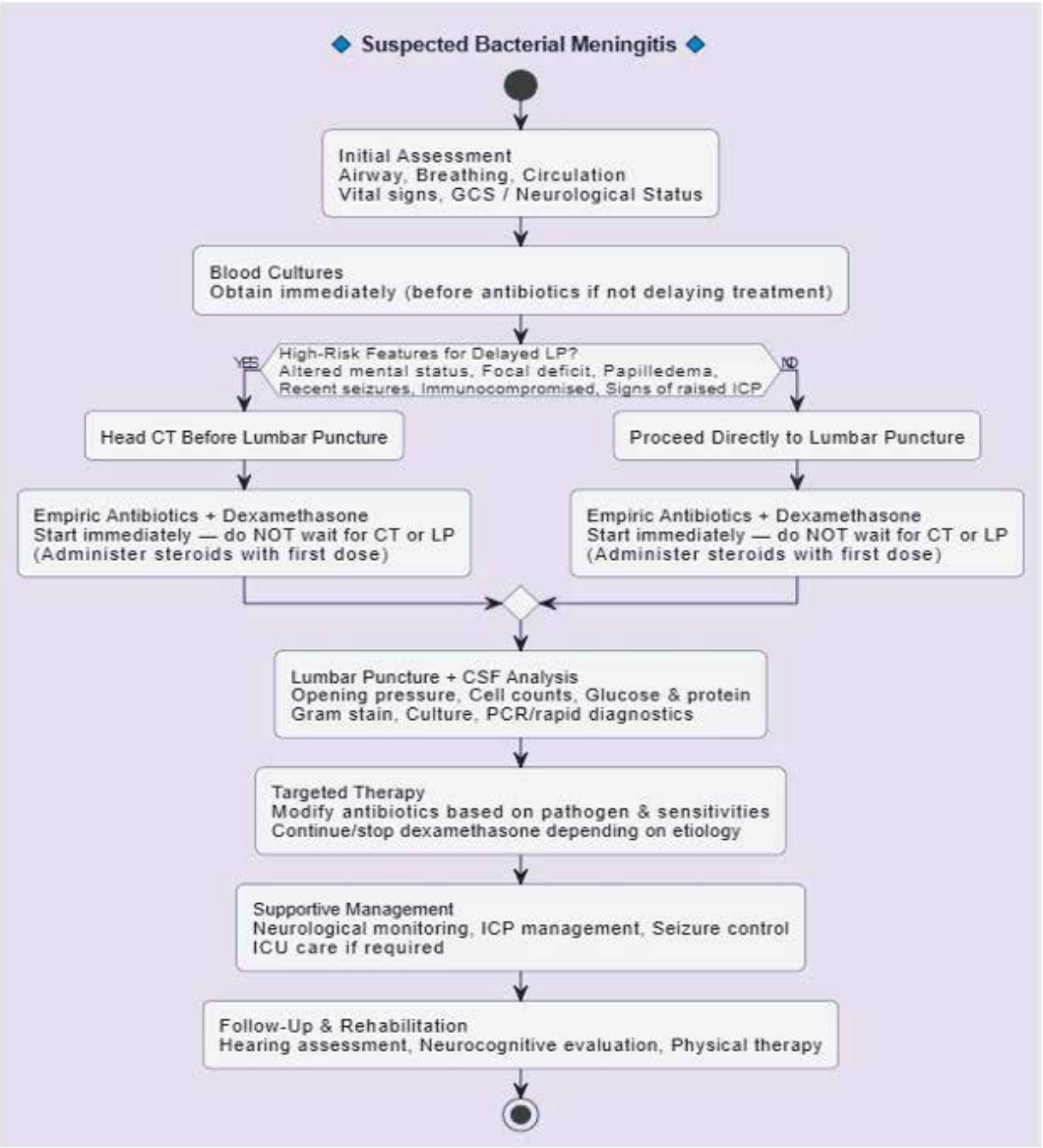

Figure 2. Evidence-based management algorithm for suspected bacterial meningitis.

GCS= Glasgow Coma Scale, **IDSA**=Infectious Diseases Society of America; **CSF**=cerebrospinal fluid; **LP**=lumbar puncture; **ICP**=intracranial pressure; **PCR**=Polymerase chain reaction.

Future Directions:

Despite advances in the acute management of bacterial meningitis, long-term neurological sequelae remain a significant challenge. Targeted research and structured interventions are essential to reduce disease burden and improve outcomes. Key areas for future exploration include:

Long-Term Follow-up Registries:

There is a critical need for national and international longitudinal registries that systematically track patients after bacterial meningitis. Such registries can

document delayed complications like cognitive impairment, hearing loss, motor deficits, evaluate recovery trajectories, and assess the effectiveness of rehabilitation interventions. These datasets may also help identify epidemiological trends, prognostic markers, and risk factors for poor outcomes across different age groups and healthcare settings.[31]

Updated Biomarkers for Early Neurological Injury:
Recent studies highlight the potential of biomarkers in predicting early neuronal injury and guiding intervention. In addition to classic markers like S100B and neuron-specific enolase (NSE), newer candidates such as glial fibrillary acidic protein (GFAP), neurofilament light chain (NfL), and inflammatory cytokine panels have shown promise in detecting blood brain barrier disruption and ongoing neuroinflammation.[33,34] Future research should focus on validating these biomarkers in prospective cohorts, integrating them with clinical scores, and assessing their utility for early neuroprotective strategies .

Artificial Intelligence and Predictive Analytics:
Artificial Intelligence (AI) offers a growing opportunity to enhance early risk prediction and personalized management in bacterial meningitis. Machine learning models can combine clinical data, neuroimaging, and laboratory parameters to identify patients at higher risk of complications. Emerging studies have demonstrated AI-driven detection of subtle neuroimaging changes such as early edema, infarcts, or hydrocephalus. Future work should focus on validating these models in multicenter cohorts and integrating AI into clinical decision-support systems to optimize individualized care.[35] Emerging evidence suggests that machine learning models using routine clinical and CSF parameters can distinguish bacterial from viral meningitis with high sensitivity (>95% for viral, ~78% for bacterial), highlighting the potential of AI-driven tools for early risk stratification and personalized management.[36]

LIMITATIONS

This review is narrative and therefore lacks the structured search, screening, and quality appraisal of a systematic review, introducing the possibility of selection bias.

Most available studies on neurological sequelae remain observational, and there is substantial heterogeneity in study populations, definitions, and outcome measures, limiting direct comparison. Despite these constraints, the review provides a coherent synthesis of recurring predictors and prevention strategies supported by current literature.

CONCLUSION

Bacterial meningitis remains a major cause of neurological disability despite improvements in acute management. Early recognition of prognostic indicators such as low GCS, delayed antibiotic initiation, and radiological abnormalities alongside timely antimicrobial therapy, adjunctive corticosteroids, and preventive vaccination, are crucial to reduce long-term sequelae.

National registries and rehabilitation pathways should be integrated into meningitis protocols in resource-limited settings. Future research should prioritize prospective evaluation of validated biomarkers for early neuronal injury, establishment of longitudinal registries to monitor long-term outcomes, and evidence-based integration of AI and predictive analytics to guide personalized interventions.

REFERENCES

1. Kloek AT, Brouwer MC, Schmand B, Tanck MWT, van de Beek D. Long-term neurologic and cognitive outcome and quality of life in adults after pneumococcal meningitis. Clin Microbiol Infect. 2020;26(10):1361-7.
2. Bijlsma MW, Brouwer MC, Bossuyt PM, Heymans MW, van der Ende A, Tanck MWT, et al. Risk scores for outcome in bacterial meningitis: systematic review and external validation study. J Infect. 2016;73(5):393-401.
3. Brouwer MC, Tunkel AR, van de Beek D. Epidemiology, diagnosis, and antimicrobial treatment of acute bacterial meningitis. Clin Microbiol Rev. 2010;23(3):467-92
4. Hasbun R. Progress and challenges in bacterial meningitis: a review. JAMA. 2022;328(21):2147-54.
5. Subramanian K, Henriques-Normark B, Normark S. Emerging concepts in the pathogenesis of Streptococcus pneumoniae: from nasopharyngeal colonizer to intracellular pathogen. Cell Microbiol. 2019;21(11):e13077.
6. Gil E, Wall E, Noursadeghi M, Brown JS. Streptococcus pneumoniae meningitis and the CNS barriers. Front Cell Infect Microbiol. 2023;12:1106596.
7. Koelman DLH, Brouwer MC, Ter Horst L, Bijlsma MW, van der Ende A, van de Beek D. Pneumococcal meningitis in adults: a prospective nationwide cohort study over a 20-year period. Clin Infect Dis. 2022;74(4):657-67.
8. Bodilsen J, Dalager-Pedersen M, Schønheyder HC, Nielsen H. Time to antibiotic therapy and outcome in bacterial meningitis: a Danish population-based cohort study. BMC Infect Dis. 2016;16:392.
9. Glimåker M, Johansson B, Halldorsdottir H, Wanecek M, Elmi-Terander A, Ghatan PH, et al. Neuro-intensive treatment targeting intracranial hypertension improves outcome in severe bacterial meningitis: an intervention-control study. PLoS One. 2014;9(3):e91976.
10. Shah HA, Jutlla G, Herrera-Restrepo O, Graham J, Hicks KA, Carrico J, et al. Public health impact of introducing a pentavalent vaccine against invasive meningococcal disease in the United States. Pharmacoeconomics. 2025;43(3):311-29.
11. Niemelä S, Lempinen L, Löyttyniemi E, Oksi J, Jero J. Bacterial meningitis in adults: a retrospective study among 148 patients over an 8-year period in a university hospital in Finland. BMC Infect Dis. 2023;23(1):45.
12. Lucas MJ, Brouwer MC, van de Beek D. Neurological sequelae of bacterial meningitis. J Infect. 2016;73(1):18-27.
13. Bai AD, Boyd JG, Li W, Campbell RJ, Gill SS. Microbiology and long-term outcomes in community-acquired, nosocomial, and post-neurosurgical meningitis with positive bacterial culture in Ontario, Canada: a population-based cohort study. Int J Infect Dis. 2025;157:107925.
14. Heckenberg SGB, Brouwer MC, van der Ende A, Hensen EF, van de Beek D. Hearing loss in adults surviving pneumococcal meningitis is associated with otitis and pneumococcal serotype. Clin Microbiol Infect. 2012;18(9):849-55.
15. Larsen FTBD, Brandt CT, Larsen L, Klastrup V, Wiese L, Helweg-Larsen J, et al. Risk factors and prognosis of seizures in adults with community-acquired bacterial meningitis in Denmark: observational cohort studies. BMJ Open. 2019;9(7):e030263.
16. Kasanmoentalib ES, Brouwer MC, van der Ende A, van de Beek D. Hydrocephalus in adults with community-acquired bacterial meningitis. Neurology. 2010;75(10):918-23.
17. Glimåker M, Naucler P, Sjölin J. Etiology, clinical presentation, outcome, and the effect of initial management in immunocompromised patients with community-acquired bacterial meningitis. J Infect. 2020;80(3):291-7.
18. van de Beek D, de Gans J, Spanjaard L, Weisfelt M, Reitsma JB, Vermeulen M. Clinical features and prognostic factors in adults with bacterial meningitis. N Engl J Med. 2004;351(18):1849-59.
19. Giede-Jeppe A, Atay S, Koehn J, Mrochen A, Luecking H, Hoelter P, et al. Neutrophil-to-lymphocyte ratio is associated with increased cerebral blood flow velocity in acute bacterial meningitis. Sci Rep. 2021;11(1):11383.
20. van de Beek D, de Gans J, Tunkel AR, Wijdicks EFM. Community-acquired bacterial meningitis in adults. N Engl J Med. 2006;354(1):44-53.
21. Gaudemer A, Covier N, Henry-Feugeas MC, Timsit JF, Lavallée PC, de Montmollin E, et al. Neuroimaging for prognosis of central nervous system infections: a systematic review and meta-analysis. Ann Intensive Care. 2025;15(1):101.
22. McGill F, Heyderman RS, Michael BD, Defres S, Beeching NJ, Borrow R, et al. The UK joint specialist societies guideline on the diagnosis and management of acute meningitis and meningococcal sepsis in immunocompetent adults. J Infect. 2016;72(4):405-38.
23. World Health Organization. Defeating meningitis by2030 [Internet]. Geneva: WHO; (cited 2025 Nov 22). Available from: https://www.who.int/initiatives/defeating-meningitis-by-2030
24. Wright C, Wordsworth R, Glennie L. Counting the cost of meningococcal disease: scenarios of

severe meningitis and septicemia. Paediatr Drugs. 2013;15(1):49-58.
25. Sabzwari S, Badini A, Fatmi Z, Shah S. Burden and associated factors for caregivers of the elderly in a developing country. East Mediterr Health J. 2016;22(6):394-403.
26. Edmond K, Clark A, Korczak VS, Sanderson C, Griffiths UK, Rudan I. Global and regional risk of disabling sequelae from bacterial meningitis: a systematic review and meta-analysis. Lancet Infect Dis. 2010;10(5):317-28.
27. Dexamethasone in adults with bacterial meningitis [Internet]. PubMed. (cited 2025 Nov 22). Available from: https://pubmed.ncbi.nlm.nih.gov/12432041/
28. Brouwer MC, Tunkel AR, van de Beek D. Epidemiology, diagnosis, and antimicrobial treatment of acute bacterial meningitis. Clin Microbiol Rev. 2010;23(3):467-92.
29. World Health Organization. Meningitis [Internet]. Geneva: WHO; (cited 2025 Nov 22). Available from: https://www.who.int/news-room/fact-sheets/detail/meningitis
30. Ladhani SN, Collins S, Djennad A, Sheppard CL, Borrow R, Fry NK, et al. Rapid increase in non-vaccine serotypes causing invasive pneumococcal disease in England and Wales, 2000-17: a prospective national observational cohort study. Lancet Infect Dis. 2018;18(4):441-51.
31. Christie S, Chan V, Mollayeva T, Colantonio A. Systematic review of rehabilitation intervention outcomes of adult and paediatric patients with infectious encephalitis. BMJ Open. 2018;8(5):e015928.
32. Grindborg Ö, Naucler P, Sjölin J, Glimåker M. Adult bacterial meningitis-a quality registry study: earlier treatment and favourable outcome if initial management by infectious diseases physicians. Clin Microbiol Infect. 2015;21(6):560-6.
33. Chekrouni N, van Soest TM, Brouwer MC, Willemse EAJ, Teunissen CE, van de Beek D. CSF neurofilament light chain concentrations predict outcome in bacterial meningitis. Neurol Neuroimmunol Neuroinflamm. 2022;9(1): e1123.
34. Gong Z, Zhang C, Li Y, Jing L, Duan R, Yao Y, et al. NLRP3 in the cerebrospinal fluid as a potential biomarker for the diagnosis and prognosis of community-acquired bacterial meningitis in adults. Front Cell Infect Microbiol. 2021;11:803186.
35. Huang Y, Moreno R, Malani R, Meng A, Swinburne N, Holodny AI, et al. Deep learning achieves neuroradiologist-level performance in detecting hydrocephalus requiring treatment. J Digit Imaging. 2022;35(6):1662-72.
36. Mentis AFA, Garcia I, Jiménez J, Paparoupa M, Xirogianni A, Papandreou A, et al. Artificial intelligence in differential diagnostics of meningitis: a nationwide study. Diagnostics (Basel). 2021;11(4):602.

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Sadiq Ali Shah; Concept, design, data collection, data interpretation, manuscript writing

All the authors have approved the final version to be published and agree to be accountable for all aspects of the work.