GMR
The Original

ASSOCIATION OF CEREBROSPINAL FLUID BIOCHEMICAL PARAMETERS WITH BLOOD AND CEREBROSPINAL FLUID CULTURE RESULTS IN NEONATAL MENINGITIS: A CROSS-SECTIONAL STUDY

Hira Tahir[1], Sadiq Amin[2], Sumaira Naz[3], Khan Salam[4], Muhammad Idrees[5], Syed Kaleem ur Rahman[6*], Zeeshan Ahmad[7]

[1,2,3,4,5] Trainee Medical Officer, Department of Pediatrics, MTI Khyber Teaching Hospital, Peshawar, Pakistan
[6]Associate Professor, Department of Pediatrics, MTI-Khyber Teaching Hospital, Peshawar, Pakistan
[7]Consultant, Department of Pediatrics, MERF DHQ Hospital, Mishti Mela, KPK, Pakistan
*Corresponding Author: Syed Kaleem ur Rahman, Email: drkalim@yahoo.com

ABSTRACT

Background: Neonatal meningitis remains a major cause of morbidity and mortality, particularly in resource limited settings where culture-based diagnosis is often limited. Cerebrospinal fluid (CSF) biochemical parameters may aid in early diagnosis, especially in culture negative cases.

Objective: To evaluate the association of CSF biochemical parameters with blood and CSF culture results in neonates with suspected meningitis.

Methodology: This cross-sectional study was conducted at Pediatric Department KTH Peshawar, from December 2025 to May 2026, including 141 neonates (0–28 days) with suspected meningitis. CSF protein, glucose, and WBC count were analyzed and categorized as normal or abnormal using standard cutoffs. Blood and CSF cultures were performed. Associations were assessed using Chi square/Fisher's exact test, and diagnostic performance was evaluated using sensitivity, specificity, predictive values, and accuracy.

Results: Abnormal CSF findings included elevated WBC (71.6%), protein (63.8%), and low glucose (56.0%). CSF and blood culture positivity were 12.1% and 18.4%, respectively. Significant associations were observed between CSF and blood culture positivity with elevated protein (p=0.018, 0.045), low glucose (p=0.021, 0.024), and elevated WBC (p=0.009, 0.031) respectively. Diagnostic performance showed high sensitivity for WBC (94.1%), protein (88.2%), and glucose (82.4%), with corresponding NPVs of 97.5%, 96.1%, and 95.2%, but low specificity.

Conclusion: CSF biochemical parameters, particularly WBC count, are useful screening markers due to their high sensitivity and negative predictive value, but their low specificity and positive predictive value limit their role in confirming neonatal meningitis. Therefore, they should be interpreted alongside clinical and microbiological findings.

KEYWORDS: Neonatal Meningitis; Cerebrospinal Fluid; Protein; Glucose.

INTRODUCTION

Neonatal meningitis is infection of meninges in neonates, diagnosed through positive cerebrospinal fluid cultures or suggestive cerebrospinal fluid analysis, particularly in context of septicemia. Mortality is high i.e. 28 - 48% in developing countries compared to ~10% in developed nations [1]. Cerebral palsy, hydrocephalus, deafness, blindness and cognitive defects are some common complications associated with neonatal meningitis. Gram-negative bacteria, such as *Escherichia coli*, *Klebsiella* spp., *Proteus* spp., *Citrobacter* spp., *Pseudomonas* spp., *Serratia* spp., *Salmonella* spp., and *Enterobacter* spp., are common causes in developing regions [2,3], while *Streptococcus agalactiae* (Group B Streptococcus) dominates in developed regions. A study conducted in Karachi found that 28.2% of neonates with sepsis were diagnosed with meningitis in which 10.2% cases were CSF culture positive, underscoring the significant burden of this disease in Pakistan [4].

Recent Pakistani studies have highlighted the diagnostic role of cerebrospinal fluid biochemical markers in meningitis. A 2023 study at Children's Hospital Lahore (140 children, 1 month 14 years) found that CSF/blood glucose ratio ≤0.31 had 90.3% sensitivity, 90.4% specificity, and 90.3% accuracy vs culture supporting the use in low resource setting for early diagnosis [5]. Another study on 113 neonates with sepsis showed mostly negative cultures but abnormal cerebrospinal fluid, mean protein of 112.5 ± 62.3 mg/dl, glucose of 36.2 ± 19.4 mg/dl and pleocytosis. cerebrospinal fluid analysis remained valuable despite negative cultures [6].

The correlation between CSF biochemical parameters and blood and CSF culture outcomes is thus essential in enhancing the accuracy of the diagnosis and clinical treatment. High CSF protein and low glucose are established markers of bacterial meningitis and they have been largely linked to poor clinical outcomes [7].
Although emerging biomarkers such as procalcitonin and lactate, as well as molecular diagnostic methods, have shown potential utility in meningitis diagnosis, their availability remains limited in many resource-constrained settings [8–10]. Thus, dependence on readily available CSF biochemical parameters is important in these settings.
This research is aimed at addressing the challenges associated with diagnosing neonatal meningitis, particularly in cases where conventional culture methods fail to identify causative pathogens despite clinical and biochemical evidence of infection. Although the biochemical parameters of CSF have been investigated in past, there are few local data exploring the relationship between the parameters and culture positivity. Given the limited local evidence regarding the diagnostic utility of CSF biochemical parameters in neonatal meningitis, this study aimed to evaluate the association between CSF protein, glucose, and WBC count abnormalities and culture positivity among neonates with suspected meningitis. In addition, the study assessed the frequency of positive blood and CSF cultures and the diagnostic performance of CSF biochemical parameters in predicting culture-confirmed infection.

METHODOLOGY

This cross-sectional study was conducted at Pediatric Department of Khyber Teaching Hospital Peshawar, from December 2025 to May 2026, after obtaining approval from hospital under Ref No: 484/DME/KMC, dated: 16/05/2025. Participant recruitment and data collection were completed during this period, followed by data analysis and manuscript preparation. Sample size was 141, calculated through OpenEpi calculator, keeping the anticipated proportion of 10.2% of patients diagnosed with meningitis having a positive cerebrospinal fluid culture [4], confidence level of 95%, and 5% margin of error. The formula used for sample size calculation is:

$$n = [DEFF*Np(1-p)]/ [(d^2/Z^2_{1-\alpha/2}*(N-1)+p*(1-p)]$$

Non probability consecutive sampling technique was used to include patients in the study. the inclusion criteria was neonates of either gender, aged 0–28 days, having clinical suspicion of meningitis (e.g., fever, lethargy, seizures, poor feeding and undergoing cerebrospinal fluid and blood sampling for meningitis workup. Neonates with major congenital anomalies, traumatic lumbar puncture, any contraindication to perform lumbar puncture, or prior antibiotics use were excluded.
Neonates were considered eligible for inclusion if they had clinical suspicion of meningitis, defined by the presence of one or more clinical features such as fever, seizures, lethargy, or poor feeding requiring CSF and blood culture evaluation. Abnormal CSF parameters were defined as protein >150 mg/dL in preterm neonates or >100 mg/dL in term neonates [11], glucose <40 mg/dL or <50% of corresponding blood glucose levels, and WBC count >30 cells/µ [12] (applied to corrected values in cases of traumatic lumbar puncture).
CSF biochemical analysis was performed in the hospital's central clinical laboratory according to standard operating procedures. CSF protein and glucose concentrations were measured using validated automated biochemical analyzers with manufacturer-recommended reagents after routine internal quality control and calibration procedures. CSF white blood cell counts were determined by standard microscopic examination according to established laboratory protocols. The interpretation of CSF biochemical parameters was based on published neonatal reference standards and current laboratory guidelines [11].
In cases of traumatic lumbar puncture, CSF WBC counts were corrected for peripheral blood contamination using the standard correction formula:

Corrected WBC = CSF WBC − (CSF RBC × blood WBC / blood RBC).

This adjustment was applied to minimize overestimation of pleocytosis due to blood contamination.
CSF and blood samples were collected under strict aseptic conditions prior to antibiotic administration. CSF protein concentration was measured using the Roche Total Protein Urine/CSF Gen.3 reagent (Catalogue No. 03333825190) on a Roche/Hitachi cobas c311/c501/c502 automated chemistry analyzer (Roche Diagnostics GmbH, Mannheim, Germany) using the benzethonium chloride turbidimetric method according to the manufacturer's instructions. CSF glucose concentration was measured using the Roche Glucose HK Gen.3 reagent (Catalogue No. 08057800190) on the same analyzer using the enzymatic hexokinase method according to the manufacturer's instructions. Total leukocyte count was determined using standard microscopic methods.
For microbiological analysis, CSF specimens were inoculated onto 5% sheep blood agar, chocolate agar, and MacConkey agar (Oxoid Ltd., Basingstoke, Hampshire, UK) and incubated at 35–37°C in a 5% CO_2 atmosphere for 48–72 hours. Blood cultures were processed using standard automated blood culture systems, with positive bottles

subcultured onto blood agar and MacConkey agar for bacterial isolation. Bacterial identification was performed using Gram staining, colony morphology, and standard biochemical tests, including catalase, coagulase, and oxidase tests [13].

Strict contamination control measures were followed, including skin disinfection with 70% alcohol and povidone-iodine before lumbar puncture and venipuncture. Isolates consistent with common skin flora (e.g., coagulase-negative *Staphylococcus* spp.) were interpreted cautiously and considered contaminants unless supported by clinical findings.

Quality assurance procedures were implemented for both biochemical and microbiological analyses to ensure accuracy and reliability of results. For CSF biochemical testing, internal quality control was maintained using manufacturer-recommended quality control materials and routine calibration of automated analyzers according to the laboratory's standard operating procedures and ISO-based quality management system [14]. Instrument calibration followed manufacturer guidelines, and reagent integrity was regularly monitored. For microbiological testing, quality control strains such as *Escherichia coli* ATCC 25922 and *Staphylococcus aureus* ATCC 25923 were used periodically to validate culture media performance and biochemical identification procedures, while sterility and performance of culture media were confirmed before use. All laboratory procedures were conducted by trained personnel in accordance with standard operating procedures (SOPs), and external quality assurance was ensured through routine supervisory review and adherence to institutional laboratory quality standards.

All eligible neonates were included irrespective of culture results. For analytical purposes, CSF culture positivity was used as the primary reference standard to evaluate associations and diagnostic performance of CSF biochemical parameters. Neonates with negative CSF cultures were retained in the study as the comparison group for statistical analysis.

Data was analyzed using SPSS version 27. Normality of continuous variables was assessed using the Shapiro–Wilk test. Variables demonstrating approximately normal distributions were summarized as mean ± standard deviation. Categorical variables were presented as frequencies and percentages. cerebrospinal fluid parameters were categorized as normal or abnormal using predefined cutoffs. Association between abnormal cerebrospinal fluid biochemical parameters and culture positivity (blood and/or CSF) was tested using Chi-square or Fisher's exact tests, as appropriate. Diagnostic performance of CSF protein, glucose, and WBC count was evaluated using CSF culture positivity as the primary reference standard, recognizing the known limitations of culture-based diagnosis in neonatal meningitis. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and overall accuracy were calculated from 2×2 contingency tables using standard diagnostic test evaluation methods. A p value ≤ 0.05 was considered statistically significant.

RESULTS

This study includes a total of 141 neonates with suspected meningitis. The mean age at admission was 13.1 ± 5.8 days, predominantly male, accounting for 88 (62.4%) cases, while females constituted 53 (37.6%). Most neonates were born at term, comprising 92 (65.2%), whereas 49 (34.8%) were preterm. The average birth weight was 2.8 ± 0.5 kg. Regarding parental education, 46 (32.6%) parents were illiterate, 51 (36.2%) had primary education, and 44 (31.2%) had secondary or higher education.

Cerebrospinal fluid analysis revealed a predominance of abnormal biochemical findings among neonates with suspected meningitis, indicating a substantial inflammatory burden. Among the parameters, elevated WBC count emerged as the most prominent alteration, suggesting it may serve as a sensitive indicator of meningeal inflammation. Increased protein levels further reflect disruption of the blood–brain barrier, while reduced glucose levels are consistent with infectious metabolic activity within the CSF (table 1).

Table 1: CSF Biochemical Parameters in Neonates with Suspected Meningitis (N=141)

Parameter	Reference Value	Mean ± SD	Normal n (%)	Abnormal n (%)
Protein (mg/dL)	≤100 (term), ≤150 (preterm)	118.4 ± 54.2	51 (36.2%)	90 (63.8%)
Glucose (mg/dL)	≥40 or ≥50% of blood glucose	38.6 ± 18.3	62 (44.0%)	79 (56.0%)
WBC (cells/µL)	≤30 (corrected value)	68.5 ± 42.7	40 (28.4%)	101 (71.6%)

Culture results indicate a relatively low prevalence of confirmed infection, with CSF culture positivity observed in 12.1% of neonates. Blood cultures were positive in 18.4% of cases, suggesting that bacteremia may accompany but does not reliably predict meningitis (table 2).

Table 2: Culture Positivity in CSF and Blood Samples

Variable	Frequency (%)
CSF Culture Positive	17 (12.1%)
CSF Culture Negative	124 (87.9%)
Blood Culture Positive	26 (18.4%)
Blood Culture Negative	115 (81.6%)

Abnormal CSF protein, glucose, and WBC levels were all significantly associated with positive CSF cultures, with p values of 0.018, 0.021, and 0.009, respectively. Among these, elevated WBC count showed the strongest association, suggesting it may be the most sensitive indicator of culture confirmed meningitis (table 3).

Table 3: Association of CSF Biochemical Parameters with CSF Culture Positivity

CSF Parameter		Culture Positive n=17 (%)	Culture Negative n=124 (%)	p value
Protein	Normal	2 (11.8%)	49 (39.5%)	0.018
	Abnormal	15 (88.2%)	75 (60.5%)	
Glucose	Normal	3 (17.6%)	59 (47.6%)	0.021
	Abnormal	14 (82.4%)	65 (52.4%)	
WBC	Normal	1 (5.9%)	39 (31.5%)	0.009
	Abnormal	16 (94.1%)	85 (68.5%)	

Note: Fisher Exact test was used. Value<0.05 is significant

Significant associations were also observed between blood culture positivity and abnormal CSF biochemical parameters. Elevated CSF protein was present in 80.8% of blood culture-positive neonates compared with 60.0% of blood culture-negative neonates (p=0.045). Similarly, low CSF glucose was more frequent among blood culture-positive cases (76.9% vs 51.3%, p=0.024). Elevated CSF WBC count showed the strongest association with blood culture positivity, occurring in 88.5% of blood culture-positive neonates compared with 67.8% of blood culture-negative neonates (p=0.031) table 4.

Table 4: Association of CSF Parameters with Blood Culture Positivity

	CSF Parameter	Blood Culture Positive n=26 (%)	Blood Culture Negative n=115 (%)	p-value
Protein	Normal	5 (19.2)	46 (40.0)	0.045[1]
	Abnormal	21 (80.8)	69 (60.0)	
Glucose	Normal	6 (23.1)	56 (48.7)	0.024[1]
	Abnormal	20 (76.9)	59 (51.3)	
WBC	Normal	3 (11.5)	37 (32.2)	0.031[2]
	Abnormal	23 (88.5)	78 (67.8)	

Note: [1] Chi-square test, [2]Fisher Exact test was used. Value<0.05 is significant

The diagnostic evaluation of CSF biochemical parameters using culture as the gold standard demonstrates that all three markers, protein, glucose, and WBC, exhibit high sensitivity and negative predictive values, indicating their usefulness in ruling out meningitis when normal. Among them, elevated WBC count was the most sensitive (94.1%) with the highest NPV (97.5%), suggesting it is the most reliable early indicator of infection. However, specificity and positive predictive values were low for all parameters, reflecting their limited ability to confirm culture positive cases alone, and highlighting the need to interpret these results in conjunction with clinical assessment and culture findings

Table 5: Diagnostic Performance of CSF Biochemical Parameters Using CSF Culture as the Primary Reference Standard

Parameter	Sensitivity % (95% CI)	Specificity % (95% CI)	PPV % (95% CI)	NPV % (95% CI)	Accuracy % (95% CI)
CSF Protein	88.2 (63.6–98.5)	39.5 (30.7–48.9)	16.7 (9.8–26.4)	96.1 (86.5–99.5)	45.4 (36.8–54.3)
CSF Glucose	82.4 (56.6–96.2)	47.6 (38.5–56.9)	17.7 (10.6–27.3)	95.2 (85.6–99.0)	51.8 (42.9–60.7)
CSF WBC	94.1	31.5	15.8	97.5	39.0

	(71.3–99.9)	(23.3–40.7)	(9.2–25.2)	(87.1–99.9)	(30.7–48.0)

Note: Positive predictive value (PPV), Negative predictive value (NPV). Confidence intervals were calculated using the Wilson method

The concordance between blood and CSF cultures was moderate, with just over half of CSF positive neonates also showing positive blood cultures. A significant proportion of meningitis cases occurred without detectable bacteremia, while most CSF negative neonates had negative blood cultures (table 5).

Table 6: Blood vs CSF Culture Concordance

Blood Culture	CSF Positive n=17 (%)	CSF Negative n=124 (%)	Total	Overall agreement	Cohen's kappa (κ)
Positive	10 (58.8%)	16 (12.9%)	26	83.7%	0.42
Negative	7 (41.2%)	108 (87.1%)	115		

DISCUSSION

This study found that CSF positivity and blood culture positivity were important factors associated with abnormal CSF biochemical parameters in neonates with suspected meningitis. WBC count in CSF was most associated with culture proven infection and best had the highest sensitivity (94.1%) and negative predictive value (97.5%). CSF protein levels and CSF to blood glucose ratio were also significantly associated with positive CSF and blood cultures. Thus, in neonates with microbiological evidence of infection these abnormalities of routine CSF biochemical parameters are often seen and may be useful supportive data in the early assessment of suspected meningitis.

This study revealed an unexpectedly high level of abnormality of CSF biochemical parameters, despite the low percentage of CSF culture positivity rate (12.1%). 71.6% of neonates had elevated WBC count, 63.8% had elevated protein and 56.0% had low glucose. Biologically, these results are plausible as inflammatory cell infiltration, changes in BBB permeability and changes in the metabolic rate of glucose have been identified in the CSF following bacterial invasion of the CNS [16]. This difference between biochemical abnormality and culture positivity could be due to the poor sensitivity of conventional culture methods and the likelihood that some cases in which there were clinical indications of infection were not cultured.

All the CSF parameters were found to have high sensitivity and relatively low specificity in the diagnostic performance analysis. The CSF WBC count had the greatest sensitivity (94.1%), followed by CSF protein (88.2%) and CSF glucose (82.4%). This sensitivity is similar to previous reports of CSF pleocytosis in bacterial meningitis of ~89–95% [16,17]. Specificity was found to be less in our study, varying from 31.5% to 47.6%, as compared to some earlier studies [16-19]. For instance, one study in Pakistan reported CSF/glucose ratio had an approximate sensitivity of 90% and specificity of 90% in the diagnosis of meningitis [5] while the CSF glucose in our study showed sensitivity 82.4% and specificity 47.6%. Our cohort exhibited a lower specificity for CSF biochemical abnormalities in culture-negative meningitis, which may indicate that biochemical abnormalities in CSF can be present in other conditions, and must be used with caution. These parameters seem to be more helpful during a normal examination to rule out meningitis than when the examination is abnormal.

Biochemical abnormalities of CSF were also significantly correlated with blood culture positivity, in addition to the correlation with CSF culture positivity. The CSF protein level was elevated in 80.8% of all blood culture-positive neonates and 60.0% of all blood culture-negative neonates, whereas the CSF WBC count was elevated in 88.5 and 67.8%, respectively. These results suggest that systemic bacterial infection often also results in inflammatory changes in CSF and hence its biochemical analysis is a useful adjunct to the evaluation of a neonate with suspected sepsis and meningitis.

A concordance analysis showed that only 58.8% of neonates with positive CSF cultures also had positive blood cultures, but 41.2% had negative blood cultures. This is similar to previous reports which have suggested that bacteremia may not be detectable in meningitis [20-22]. Clinically, this is a reminder that there are limitations to relying on blood culture results alone and the role of CSF evaluation in the case of suspected meningitis.

The very low false-negative rates for CSF WBC count (97.5%), protein (96.1%), and glucose (95.2%) from a clinical perspective indicate that normal CSF parameters significantly reduce the risk for culture-proven meningitis. This could be especially helpful in areas with limited resources where confirmation diagnostic tests are not easily accessible. The low positive predictive values (15.8%, 16.7%, and 17.7% for WBC count, protein, and glucose, respectively) mean that abnormal values are poor evidence of infection. Hence, CSF biochemical parameters should be viewed as supportive tests to help guide decision making and should not be interpreted as a diagnostic test.

The high proportion of term neonates to the total number, in our study, was found to be different to some previous studies that reported higher proportions of term neonates with meningitis, ranging up to 70% in some populations [23]. The variation may be attributed to the differences in referral pattern, population characteristics, and healthcare

settings. However, the clinical signs seen in our study, such as fever, seizures, lethargy and nonfeeding are similar to those previously reported for neonatal meningitis [7,24,25].

LIMITATIONS AND FUTURE IMPLICATIONS

There are some of limitations to this study. Because of its single-center design, small sample size and consecutive non-probability sampling, findings may limit the generalizability and may contain selection bias. Moreover, CSF culture was employed as the reference test when it has been demonstrated that there are limitations in the sensitivity of this technique. This means that some neonates with true infection may have been misclassified as culture negative and this may lead to underestimation of the infection rates, affecting diagnostic performance estimates. Furthermore, molecular diagnostic methods and newer biomarkers were not evaluated in this study. The results of this study support future multicenter studies with larger numbers of cases and more sophisticated diagnostic methods to confirm the results and enhance the accuracy of the diagnosis of neonatal meningitis. The CSF biochemical parameters may be useful supportive diagnosis, but should not be relied on as definitive diagnosis for meningitis. The results of their investigations should be used in conjunction with clinical assessment and microbiological investigations, especially when there is no culture result or when it is delayed.

CONCLUSION

Abnormal CSF biochemical parameters, particularly elevated WBC count, were significantly associated with both CSF and blood culture positivity in neonates with suspected meningitis. Among the evaluated markers, CSF WBC count demonstrated the highest sensitivity and negative predictive value, indicating its usefulness as an early screening marker. However, the low specificity and positive predictive values of CSF WBC, protein, and glucose limit their ability to confirm infection independently. Therefore, CSF biochemical parameters should be interpreted alongside clinical assessment and microbiological findings to support the diagnosis of neonatal meningitis.

REFERENCES

1. Duffy N, Koirala A, Williams PC. Epidemiology and outcomes of culture-proven neonatal meningitis in Australian tertiary hospitals: a multicenter retrospective cohort study. Pediatr Infect Dis J. 2026;45(10):193-195. doi:10.1097/INF.0000000000005131.
2. Zainel A, Mitchell H, Sadarangani M. Bacterial meningitis in children: neurological complications, associated risk factors, and prevention. Microorganisms. 2021;9(3):535. doi:10.3390/microorganisms9030535.
3. Ali SA, Taj MK, Ali SH. Antimicrobial resistance pattern of bacterial meningitis among patients in Quetta, Pakistan. Infect Drug Resist. 2021;14:5107-5120. doi:10.2147/IDR.S339231.
4. Ahmed S, Akhtar S, Sultan A, Rehman AU. Frequency, risk factors, and outcome of neonatal meningitis in sepsis. Pak J Med Sci. 2024;40(9):1964-1968. doi:10.12669/pjms.40.9.8890.
5. Raza AB, Safder MR, Khalid N. Diagnostic accuracy of CSF and blood glucose ratio in diagnosis of bacterial meningitis in children using CSF culture as gold standard. Pak J Med Health Sci. 2023;17(12):61-64. doi:10.53350/pjmhs02023171261.
6. Afridi JK, Karim R, Idrees M, Yar S, Lala GE, Gul H. Assessment of neonatal meningitis in a unique presentation with sepsis. J Postgrad Med Inst. 2023;37(2):130-134.
7. You D, Wang X, Lu P, Li F. Early prognostic value of repeat CSF parameter measurements in neonatal bacterial meningitis following initial antimicrobial therapy. Ital J Pediatr. 2025;51(1):166. doi:10.1186/s13052-025-02000-z.
8. Borowiak A, Safranow K, Sarna A, Łoniewska B. Diagnostic utility of procalcitonin and lactate determination in cerebrospinal fluid for the diagnosis of neonatal meningitis. J Clin Med. 2025;14(2):414. doi:10.3390/jcm14020414.
9. Goktug A, Gundogdu IA, Besli E. Clinical impact of cerebrospinal fluid multiplex polymerase chain reaction testing in children with suspected central nervous system infection. Medeniyet Med J. 2025;40(3):128-135. doi:10.4274/mmj.galenos.2025.43895.
10. Al Sayyed BH, Covington K, Nicoski P, Feffer M, Heyn M, McElroy GH, et al. The utility of using FilmArray meningitis encephalitis PCR panel in children admitted with meningitis and encephalitis at LUMC: is it a useful diagnostic stewardship tool? Open Forum Infect Dis. 2025;12(Suppl 1):ofae631.1754.
11. doi:10.1093/ofid/ofae631.1754.
12. Çakır SÇ, Dorum BA, Özkan H, Köksal N, Kocael F, Budak F, et al. Investigation of the diagnostic value of cerebrospinal fluid and serum sTREM-1 levels in neonatal meningitis. Children (Basel). 2024;11(8):1026. doi:10.3390/children11081026.
13. Zhao Z, Hua X, Yu J, Zhang H, Li J, Li Z. Duration of empirical therapy in neonatal bacterial meningitis with third generation cephalosporin: a multicenter retrospective study. Arch Med Sci. 2019;15(6):1482-9. doi:10.5114/aoms.2018.76938.

14. Liu S. Neonatal meningitis. In: Lewis SL, editor-in-chief. MedLink Neurology. San Diego (CA): MedLink LLC; Updated 2024 Feb 24. Available from: https://www.medlink.com
15. Oyekale OT, Ojo BO, Olajide AT, Oyekale OI. Bacteriological profile and antibiogram of blood culture isolates from bloodstream infections in a rural tertiary hospital in Nigeria. Afr J Lab Med. 2022;11(1):1807.
16. doi:10.4102/ajlm.v11i1.1807.
17. Gruber L, Hausch A, Mueller T. Internal quality controls in the medical laboratory: A narrative review of the basic principles of an appropriate quality control plan. Diagnostics (Basel). 2024;14(19):2223. doi:10.3390/diagnostics14192223.
18. O'Leary C, Pittet LF, Beaumont R, Constable L, Daley A, Hodge I, et al. Predictive performance of cerebrospinal fluid parameters for diagnosis of meningitis in infants: a cohort study. Arch Dis Child. 2025;110(3):209-215. doi:10.1136/archdischild-2024-327628.
19. Huang H, Tan J, Gong X, Li J, Wang L, Xu M, et al. Comparing single vs combined cerebrospinal fluid parameters for diagnosing full-term neonatal bacterial meningitis. Front Neurol. 2019;10:12. doi:10.3389/fneur.2019.00012.
20. Li Y, Xiao R, Zou P, Du Y, Lu Q, Cui J, et al. RT-PCR in the early detection and monitoring of pathogen residual status in neonatal bacterial meningitis. iLABMED. 2024;2(4):307-315. doi:10.1002/ila2.55.
21. Ghoweba Y, Shabestari SA, Malik ZA. Diagnostic accuracy of cerebrospinal fluid multiplex polymerase chain reaction panel testing in patients with suspected central nervous system infections: a multicenter study in the United Arab Emirates. Cureus. 2024;16(1):e51906. doi:10.7759/cureus.51906.
22. Anne RP, Dutta S, Balasubramanian H, Aggarwal AN, Chadha N, Kumar P. Meta-analysis of cerebrospinal fluid cell count and biochemistry to diagnose meningitis in infants aged <90 days. Am J Perinatol. 2024;41(Suppl 1):e1962-e1975. doi:10.1055/a-2095-6729.
23. Bushaala N, Elshibani H, Algazal N, Elfergani M. Role of CSF C-reactive protein in rapid diagnosis and differentiation of different forms of meningitis in children. Sch Acad J Biosci. 2024;12(7):209-219. doi:10.36347/sajb.2024.v12i07.005.
24. Mesilhy R, Safra I, Alnaimi S, Ali A, Terkawi R, Gaffari M, et al. Determinants of prolonged antibiotic administration in culture-negative evaluations of early-onset neonatal meningitis: a retrospective cohort study. Antibiotics (Basel). 2025;14(9):925. doi:10.3390/antibiotics14090925.
25. Buttera M, Mazzotti S, Zini T, Corso L, Dallai V, Miselli F, et al. Bacterial meningitis in infants under 90 days of age: a retrospective single-center study. Children (Basel). 2024;11(12):1411. doi:10.3390/children11121411.
26. Ong LT, Chee NM, Loh AJ, Balasubramaniam R. Neurological manifestations and complications of neonatal meningitis: a systematic review and meta-analysis. J Neonatol. 2025;39(3):265-278. doi:10.1177/09732179241274110.
27. Oncel MY, Cizmeci MN, Karadag Oncel E, Elvan Tuz A, Canpolat FE, Akin MA, et al. Epidemiology and outcomes of neonatal meningitis: results of the Turkish Neo Meningitis nationwide study. Pediatr Infect Dis J. 2024;43(4):365-370. doi:10.1097/INF.0000000000004197.