

Microbiology, Treatment, and Outcomes of Ventriculoperitoneal Shunt Infections

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ABSTRACT

Ventriculoperitoneal shunt infection is a serious complication of hydrocephalus treatment and may require prolonged antimicrobial therapy, repeated surgery, and temporary cerebrospinal fluid diversion. This study evaluated the clinical characteristics, microbiological profile, treatment strategies, and outcomes of ventriculoperitoneal shunt infections, with particular emphasis on gram-negative involvement and recurrence.

This retrospective cohort study included 36 patients treated for a first documented ventriculoperitoneal shunt infection at a tertiary referral center between January 2016 and December 2023. Demographic, clinical, microbiological, treatment, and outcome data were reviewed. Patients with positive cerebrospinal fluid cultures were compared according to the presence of gram-negative organisms.

Cerebrospinal fluid cultures were positive in 32 patients (88.9%). *Staphylococcus* species were identified in 68.8%, gram-negative organisms in 43.8%, and polymicrobial infection in 40.6%. Gram-negative involvement was associated with more frequent polymicrobial infection (64.3% vs 22.2%; $p = 0.029$), longer time to cerebrospinal fluid sterilization (28.5 vs 14.0 days; $p = 0.030$), and longer hospitalization (60.5 vs 32.0 days; $p = 0.026$). Recurrent infection occurred in 17 of 35 evaluable patients (48.6%). Positive wound swab cultures were more frequent among patients with recurrence (52.9% vs 11.1%; $p = 0.012$; unadjusted odds ratio, 9.00).

Gram-negative involvement in ventriculoperitoneal shunt infections was associated with a more prolonged treatment course but not with recurrence. Positive wound swab culture may be a marker of recurrent infection. Larger prospective studies are needed to confirm these findings and optimize management strategies.

Keywords: cerebrospinal fluid; gram-negative bacteria; hydrocephalus; recurrence; shunt infection; ventriculoperitoneal shunt

Introduction

Ventriculoperitoneal (VP) shunting remains a mainstay of treatment for hydrocephalus; however, cerebrospinal fluid (CSF) shunt infection is one of its most serious complications. CSF shunt infections occur in approximately 5%–15% of shunt procedures and commonly require prolonged antimicrobial therapy, shunt removal or replacement, temporary external CSF drainage, and repeated surgery, resulting in substantial morbidity and prolonged hospitalization (1-3). Despite combined surgical and antimicrobial management, reinfection remains an important clinical problem, with pediatric series reporting rates of approximately 12%–26% (4).

The management of CSF shunt infections remains challenging despite advances in neurosurgical techniques and antimicrobial therapy. Successful treatment generally requires a combination of appropriate antimicrobial therapy, removal of

infected shunt hardware, temporary CSF diversion when indicated, and delayed shunt replacement after infection control. However, considerable variability persists regarding the optimal surgical strategy, duration of antimicrobial therapy, timing of shunt reimplantation, and the role of intraventricular antimicrobial therapy, with the available evidence derived largely from observational studies (2, 5, 6).

Although coagulase-negative *staphylococci* and *Staphylococcus aureus* remain the predominant pathogens in CSF shunt infections, gram-negative bacilli also account for a clinically important proportion of cases (1, 5). Microbial virulence, biofilm formation, and antimicrobial susceptibility may influence the clinical course and treatment response (7-9). However, available studies have more commonly focused on pathogen distribution, antimicrobial selection, or overall treatment outcomes, whereas evidence directly linking microbiological characteristics with time to

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CSF sterilization, treatment intensity, and recurrence remains limited (1, 4).

Therefore, the present study aimed to describe the demographic and clinical characteristics, microbiological profile, treatment strategies, and clinical outcomes of patients treated for VP shunt infections at a tertiary referral center. We further explored whether gram-negative involvement was associated with a more prolonged treatment course, particularly longer time to CSF sterilization and hospitalization, as well as recurrent infection.

Material and Methods

Study Design and Population: This retrospective cohort study screened 51 patients of any age who were treated for ventriculoperitoneal (VP) shunt infection at a tertiary referral center between January 2016 and December 2023. After application of the predefined eligibility criteria, 36 patients were included in the final analysis. This study was approved by the institutional ethics committee on March 27, 2024 (decision no. 2024/010.99/2/43). Because of the retrospective design, the requirement for individual informed consent was waived, and all patient data were anonymized before analysis.

Patients of any age were eligible if they had a VP shunt in place, were treated at our institution for a confirmed or clinically probable VP shunt infection during the study period, and had sufficient clinical, microbiological, treatment, and outcome data. For the assessment of recurrent infection, surviving patients were required to have at least 1 year of follow-up. VP shunt infection was diagnosed on the basis of compatible clinical findings together with microbiological growth from CSF, shunt-tip, or wound specimens. Culture-negative cases were also eligible when shunt infection was considered the most likely diagnosis after joint evaluation by the neurosurgery and infectious diseases teams and no alternative infectious focus was identified.

For patients with more than one documented shunt infection during the study period, only the first infection episode was included as the index episode. Patients were excluded if they had an infection limited to a temporary CSF drainage device without VP shunt involvement, mechanical shunt dysfunction without evidence of infection, community-acquired meningitis considered unrelated to the shunt, isolated microbiological growth judged to represent contamination in the absence of compatible clinical or CSF findings, or

insufficient clinical, microbiological, treatment, or outcome data to confirm the diagnosis.

Data Collection: Demographic, clinical, microbiological, laboratory, treatment, and outcome data were retrospectively extracted from electronic medical records. Collected variables included age, sex, underlying neurological condition, indication for shunt placement, presenting signs and

symptoms, shunt dysfunction, acute hydrocephalus, ventriculitis or meningitis, and local inflammatory findings or wound dehiscence.

Laboratory variables included peripheral blood leukocyte, neutrophil, lymphocyte, and monocyte counts; C-reactive protein; procalcitonin; CSF leukocyte count; CSF glucose; and CSF protein. Laboratory values that were not measured during the index infection episode were treated as missing and were not imputed.

Microbiological data were obtained from CSF, shunt-tip, wound swab, and blood or intravascular catheter-derived cultures. Because peripheral blood and intravascular catheter-derived cultures were not consistently distinguished in the medical records, they were analyzed together as a single composite variable, defined as any positive blood/intravascular catheter culture. Microbiological samples, particularly CSF and blood cultures, were generally obtained before the initiation of systemic antimicrobial therapy whenever clinically feasible. However, because of the retrospective design, prior antimicrobial exposure could not be reliably verified for every patient.

Microbiological Classification: The microbiological profile was primarily evaluated using organisms isolated from CSF cultures. Organisms were classified as *Staphylococcus* species, gram-negative organisms, *Enterococcus* species, or *Candida* species according to microbiological identification. Because more than one organism could be isolated from the same patient during the index infection episode, these categories were not mutually exclusive. CSF infections were classified as polymicrobial when more than one distinct microorganism was isolated from CSF during the index infection episode. Different microbiological designations referring to the same organism were considered a single isolate. Wound swab culture positivity was defined as microbial growth from a specimen obtained from the surgical wound or along the shunt tract during the index infection episode.

For the principal microbiological subgroup analysis, patients with positive CSF cultures were categorized according to the presence or absence of at least one gram-negative organism. Patients with culture-negative CSF were not included in this subgroup comparison.

Treatment Variables: Treatment data included systemic antimicrobial agents, total duration of systemic antimicrobial therapy, intraventricular antimicrobial treatment, duration of intraventricular therapy, use of an external ventricular drain or reservoir, and surgical management.

Final surgical management was classified into three mutually exclusive categories:

1. **One-stage shunt replacement**, defined as removal of the infected shunt and placement of a new shunt during the same surgical session;
2. **Two-stage shunt replacement**, defined as removal of the infected shunt, temporary CSF diversion, and delayed placement of a new shunt after infection control;
3. **Shunt removal without subsequent replacement.**

The choice between one-stage and two-stage shunt replacement was not governed by a formal institutional protocol and was based on individual clinical judgment.

When more than one procedure was performed during hospitalization, patients were classified according to the final surgical strategy used for management of the index infection episode.

Outcomes and Definitions: The primary outcomes were time to CSF sterilization, length of hospital stay, recurrent shunt infection, and mortality during the index treatment period.

Follow-up CSF cultures were routinely obtained at approximately 48-hour intervals during treatment. At our institution, CSF sterilization was confirmed by three consecutive negative cultures. Time to CSF sterilization was defined as the number of days from initiation of antimicrobial therapy to the first of these three consecutive negative cultures. Patients without a documented sterilization interval were excluded from analyses involving this outcome.

Recurrence was defined as a subsequent shunt infection diagnosed after completion of treatment for the index infection episode. Follow-up information was obtained from medical records. Patients without documented recurrence during

follow-up were classified as recurrence-free. Follow-up duration was calculated from hospital discharge to the date of the most recent clinical contact.

Because the exact date of recurrence was not available for all recurrent cases, recurrence was analyzed as a binary outcome rather than by time-to-event methods. The patient who died during treatment of the index infection was included in the overall cohort and mortality analysis but excluded from the recurrence analysis.

Statistical Analysis: All statistical analyses were performed using IBM SPSS Statistics, version 26.0 (IBM Corp., Armonk, NY, USA). The distribution of continuous variables was assessed using the Shapiro–Wilk test. Continuous variables were presented as median (Q1–Q3), and categorical variables were summarized as frequencies and percentages.

Comparisons between two independent groups were performed using the Mann–Whitney U test for continuous variables. Binary categorical variables were compared using Fisher’s exact test because of the small sample size and low expected cell frequencies. Categorical variables with more than two levels, including final surgical management strategy, were compared using the Fisher–Freeman–Halton exact test.

Among patients with positive CSF cultures, clinical, microbiological, treatment, and outcome variables were compared according to the presence or absence of at least one gram-negative organism. Exploratory comparisons were also performed between patients with and without recurrent infection. The patient who died during treatment of the index infection was excluded from the recurrence analysis. The association between initial CSF protein concentration and time to CSF sterilization was evaluated using Spearman’s rank correlation coefficient.

Missing data were handled using available-case analysis and were not imputed. All statistical tests were two-tailed, and a p value <0.05 was considered statistically significant.

Results

Study Population and Clinical Presentation:

Of the 51 patients initially screened, 15 were excluded according to the predefined eligibility criteria, and 36 patients with a first documented episode of VP shunt infection were included in the final analysis. Eighteen patients (50.0%) were female and 18 (50.0%) were male. The median age

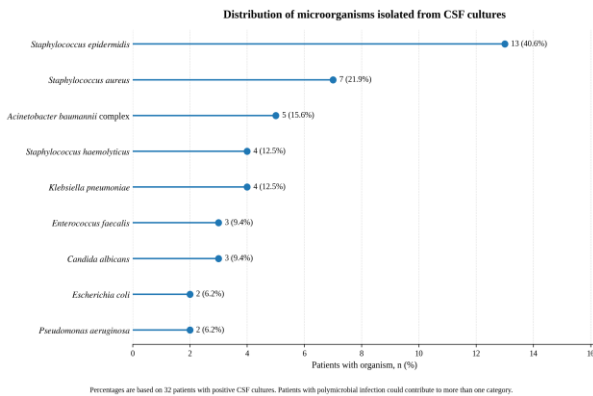


Fig. 1. Distribution of microorganisms isolated from cerebrospinal fluid cultures in patients with ventriculoperitoneal shunt infection. Percentages were calculated among the 32 patients with positive CSF cultures. Patients with polymicrobial infections could contribute to more than one microorganism category.

was 0.92 years (Q1–Q3, 0.38–16.75 years), and 27 patients (75.0%) were younger than 18 years.

The underlying causes of hydrocephalus included congenital central nervous system malformations in 14 patients (38.9%), brain tumors in 6 (16.7%), previous central nervous system infection in 4 (11.1%), and intraventricular hemorrhage in 2 (5.6%). The underlying etiology could not be clearly classified in the remaining 10 patients (27.8%).

The most frequent presenting feature was local inflammation along the shunt tract, wound dehiscence, or exposed hardware, which was observed in 12 patients (33.3%). Other presenting findings included vomiting in 7 patients (19.4%), fever in 5 (13.9%), seizures in 5 (13.9%), headache in 3 (8.3%), acute hydrocephalus in 3 (8.3%), and ventriculitis or meningitis in 3 (8.3%). Abdominal pain was documented in 1 patient (2.8%). Baseline demographic and clinical characteristics are summarized in Table 1.

Microbiological Findings: CSF cultures were positive in 32 of 36 patients (88.9%). Shunt-tip cultures were positive in 27 patients (75.0%), wound swab cultures in 11 (30.6%), and blood/intravascular catheter-derived cultures in 25 (69.4%). Among the four patients with negative CSF cultures, three had microbiological confirmation from shunt-tip and/or wound cultures, whereas the remaining patient was diagnosed on the basis of exposed shunt hardware and compatible clinical findings.

Among the 32 patients with positive CSF cultures, monomicrobial infection was identified in 19 patients (59.4%) and polymicrobial infection in 13 (40.6%). Different microbiological designations

referring to the same microorganism were counted as a single isolate.

Staphylococcus species were identified in the CSF of 22 patients (68.8%), whereas at least one gram-negative organism was isolated in 14 (43.8%). *Candida* species were identified in 4 patients (12.5%) and *Enterococcus* species in 3 (9.4%). Because polymicrobial infections could include microorganisms from more than one category, these groups were not mutually exclusive. The distribution of microorganisms isolated from CSF cultures is shown in Figure 1.

Treatment Strategies: All patients underwent surgical treatment in addition to systemic antimicrobial therapy. The median duration of systemic antimicrobial therapy was 22 days (Q1–Q3, 16.75–40 days). Final surgical management consisted of one-stage shunt replacement in 12 patients (33.3%), two-stage shunt replacement in 22 (61.1%), and shunt removal without subsequent replacement in 2 (5.6%). Temporary CSF diversion with an external ventricular drain or reservoir was used in 23 patients (63.9%).

Among the 32 patients with positive CSF cultures, six (18.8%) received intraventricular antimicrobial therapy. All six patients had gram-negative involvement, compared with 8 of 26 patients who did not receive intraventricular therapy (100% vs 30.8%; Fisher's exact test, $p = 0.003$). Colistin was administered in five patients and amikacin in one. The median duration of intraventricular therapy was 20.5 days (Q1–Q3, 9.75–21.75 days; range, 9–45 days).

Clinical Outcomes: Among the 32 patients with positive CSF cultures, the median time to CSF sterilization was 19.5 days (Q1–Q3, 11.5–30.5 days; range, 4–69 days). The median length of hospital stay in the entire cohort was 43.5 days (Q1–Q3, 28.75–65.75 days; range, 8–243 days).

Among the 35 evaluable patients, 17 (48.6%) developed recurrent VP shunt infection and 18 (51.4%) remained recurrence-free. One patient died during treatment of the index infection. Microbiological characteristics, treatment strategies, and clinical outcomes are summarized in Table 2.

Outcomes According To Gram-Negative Involvement:

Among the 32 patients with positive CSF cultures, 14 had at least one gram-negative organism isolated, whereas the remaining 18 had no gram-negative involvement (Table 3).

Polymicrobial CSF infection was more frequent among patients with gram-negative involvement than among those without gram-negative

Table 1: Baseline Demographic and Clinical Characteristics of The Study Cohort (n = 36)

Variable	Value
Demographic characteristics	
Age, years	0.92 (0.38–16.75)
Pediatric patients (<18 years)	27 (75.0)
Female sex	18 (50.0)
Etiology of hydrocephalus	
Congenital CNS malformation	14 (38.9)
Tumor-related hydrocephalus	6 (16.7)
Postinfectious hydrocephalus	4 (11.1)
Posthemorrhagic hydrocephalus	2 (5.6)
Unknown etiology	10 (27.8)
Clinical presentation	
Local inflammatory findings, wound dehiscence, or exposed hardware	12 (33.3)
Vomiting	7 (19.4)
Fever	5 (13.9)
Seizure	5 (13.9)
Ventriculitis/meningitis	3 (8.3)
Acute hydrocephalus	3 (8.3)
Headache	3 (8.3)
Abdominal pain	1 (2.8)

Data are presented as n (%) for categorical variables and median (Q1–Q3) for continuous variables. Clinical presentation variables were not mutually exclusive. CNS, central nervous system

involvement (9/14 [64.3%] vs 4/18 [22.2%], $p = 0.029$). Patients with gram-negative CSF infection had a significantly longer time to CSF sterilization than patients without gram-negative involvement. The median sterilization time was 28.5 days (Q1–Q3, 21.25–36.5 days) in the gram-negative group and 14.0 days (Q1–Q3, 10–22 days) in the non-gram-negative group (Mann–Whitney U test, $p = 0.030$).

Hospitalization was also significantly longer among patients with gram-negative infection. The median length of hospital stay was 60.5 days (Q1–Q3, 35.5–92.75 days) in patients with gram-negative organisms and 32.0 days (Q1–Q3, 22.75–55 days) in those without gram-negative organisms ($p = 0.026$).

Positive blood or intravascular catheter-derived cultures were more frequent in patients with gram-negative CSF infection than in those without gram-negative involvement (13/14 [92.9%] vs 9/18 [50.0%]; Fisher's exact test, $p = 0.019$).

Two-stage shunt replacement was performed in 12 of 14 patients (85.7%) with gram-negative infection and in 9 of 18 patients (50.0%) without gram-negative infection. However, the overall distribution of final surgical management did not

differ significantly between the groups ($p = 0.076$). Similarly, shunt-tip culture positivity was more frequent in the gram-negative group (13/14 [92.9%] vs 11/18 [61.1%], $p = 0.053$).

Recurrent infection did not differ between surviving patients with and without gram-negative involvement (7/13 [53.8%] vs 8/18 [44.4%], $p = 0.722$). Because the patient who died was excluded, recurrence was compared among the surviving patients.

Factors Associated With Recurrent Infection:

The recurrence analysis included 35 patients after exclusion of the patient who died during treatment of the index infection. Seventeen patients developed recurrent infection and 18 remained recurrence-free.

Positive wound swab cultures were significantly more frequent among patients who developed recurrence than among those who remained recurrence-free (9/17 [52.9%] vs 2/18 [11.1%]; Fisher's exact test, $p = 0.012$). The corresponding unadjusted odds ratio was 9.00 (95% CI, 1.56–51.87).

No statistically significant differences were identified between the recurrence and recurrence-free groups regarding age, sex, underlying

Table 2: Microbiological Characteristics, Treatment Strategies, and Clinical Outcomes of The Study Cohort (n = 36)

Variable	Value
Microbiological findings	
Positive CSF culture	32 (88.9)
Positive shunt-tip culture	27 (75.0)
Positive wound swab culture	11 (30.6)
Positive blood or intravascular catheter-derived culture	25 (69.4)
CSF microbiology (n = 32)	
Monomicrobial infection	19 (59.4)
Polymicrobial infection	13 (40.6)
<i>Staphylococcus spp.</i> ^a	22 (68.8)
Gram-negative organisms ^a	14 (43.8)
<i>Candida spp.</i> ^a	4 (12.5)
<i>Enterococcus spp.</i> ^a	3 (9.4)
Treatment strategies	
One-stage shunt replacement	12 (33.3)
Two-stage shunt replacement	22 (61.1)
Shunt removal without replacement	2 (5.6)
Temporary CSF diversion with EVD or reservoir	23 (63.9)
Duration of systemic antimicrobial therapy, days	22 (16.75–40)
Intraventricular antimicrobial therapy	6 (16.7)
Duration of intraventricular antimicrobial therapy, days (n = 6)	20.5 (9.75–21.75)
Clinical outcomes	
Time to CSF sterilization, days (n = 32)	19.5 (11.5–30.5)
Length of hospital stay, days	43.5 (28.75–65.75)
Recurrent infection during follow-up (n = 35)	17 (48.6)
Death during index treatment	1 (2.8)
Follow-up duration among survivors, months (n = 35)	70.9 (57.9–85.8)

Data are presented as n (%) for categorical variables and median (Q1–Q3) for continuous variables. Percentages were calculated using the overall cohort of 36 patients unless a different denominator is indicated. ^aPatients with polymicrobial CSF infections could contribute to more than one microorganism category; therefore, microorganism categories were not mutually exclusive. Recurrence analysis excluded the patient who died during the index infection. CSF, cerebrospinal fluid; EVD, external ventricular drain

neurological diagnosis, shunt dysfunction, presenting symptoms, CSF culture positivity, shunt-tip culture positivity, blood or intravascular catheter culture positivity, polymicrobial infection, gram-negative involvement, surgical treatment strategy, temporary external CSF diversion, or intraventricular antimicrobial therapy.

The median time to CSF sterilization was 25 days (Q1–Q3, 6–35 days) among patients with recurrence and 21 days (Q1–Q3, 17–39.25 days) among recurrence-free patients ($p = 0.355$). The corresponding median lengths of hospital stay were 46 days (Q1–Q3, 29–65 days) and 37.5 days (Q1–Q3, 27.25–61.75 days), respectively ($p = 0.668$).

Initial CSF protein levels were available in 27 patients. Median CSF protein was lower among patients who subsequently developed recurrence than among recurrence-free patients (225 mg/dL [Q1–Q3, 58–619 mg/dL] vs 665.5 mg/dL [Q1–Q3, 302.5–1009 mg/dL]), although the difference did not reach statistical significance ($p = 0.055$). Given the incomplete laboratory data and the exploratory nature of this comparison, this finding was interpreted cautiously. Among the 25 patients with both initial CSF protein measurements and an evaluable CSF sterilization interval, there was no statistically significant correlation between initial CSF protein level and time to CSF sterilization (Spearman's $\rho = 0.277$, $p = 0.180$).

Table 3: Clinical, Microbiological, Treatment, and Outcome Characteristics According To Gram-Negative Involvement Among Patients With Positive CSF Cultures

Variable	Gram-negative organism present (n = 14)	Gram-negative organism absent (n = 18)	p value
Demographic characteristics			
Age, years	1.50 (0.46–20.25)	0.79 (0.29–11.25)	0.518
Female sex	9 (64.3)	9 (50.0)	0.490
Microbiological findings			
Polymicrobial CSF infection	9 (64.3)	4 (22.2)	0.029
Positive blood/intravascular catheter-derived culture	13 (92.9)	9 (50.0)	0.019
Positive shunt-tip culture	13 (92.9)	11 (61.1)	0.053
Positive wound swab culture	3 (21.4)	6 (33.3)	0.694
Treatment strategies			
Final surgical management			
One-stage shunt replacement	2 (14.3)	7 (38.9)	
Two-stage shunt replacement	12 (85.7)	9 (50.0)	0.076 [†]
Shunt removal without replacement	0 (0.0)	2 (11.1)	
Temporary CSF diversion with EVD or reservoir	12 (85.7)	10 (55.6)	0.124
Intraventricular antimicrobial therapy	6 (42.9)	0 (0.0)	0.003
Clinical outcomes			
Time to CSF sterilization, days	28.5 (21.25–36.5)	14.0 (10.0–22.0)	0.030
Length of hospital stay, days	60.5 (35.5–92.75)	32.0 (22.75–55.0)	0.026
Recurrent infection among survivors	7/13 (53.8)	8/18 (44.4)	0.722
Death during index treatment	1 (7.1)	0 (0.0)	0.438

Data are presented as n (%) for categorical variables and median (Q1–Q3) for continuous variables. Continuous variables were compared using the Mann–Whitney U test, and categorical variables were compared using Fisher’s exact test. [†] p = 0.076 refers to the overall comparison of the three final surgical management categories using the Fisher–Freeman–Halton exact test. Recurrence analysis excluded the patient who died during treatment of the index infection. Statistically significant p values are shown in bold. CSF, cerebrospinal fluid; EVD, external ventricular drain

Discussion

In this single-center cohort of patients with VP shunt infection, staphylococci remained the predominant microorganisms, although gram-negative and polymicrobial infections also accounted for a substantial proportion of culture-positive episodes. Gram-negative involvement was associated with a longer time to CSF sterilization, a prolonged hospital stay, and a higher frequency of positive blood or intravascular catheter-derived cultures. Intraventricular antimicrobial therapy was administered only to patients with gram-negative infection, reflecting its selective use in this subgroup. Nearly half of the evaluable patients developed recurrent infection during follow-up. Recurrence was not associated with surgical strategy, gram-negative involvement, or time to CSF sterilization; however, positive wound swab cultures were significantly more common among patients who later developed recurrence.

The predominance of *Staphylococcus* species in our cohort is consistent with pediatric series in which gram-positive organisms, particularly staphylococci, predominate, while gram-negative pathogens remain clinically important and may be associated with greater disease severity (1, 10). In our cohort, gram-negative and polymicrobial infections were relatively frequent. Direct comparisons should be made cautiously, as patients with polymicrobial infections could contribute to more than one microorganism category in our analysis.

Gram-negative infection was associated with a median time to CSF sterilization that was approximately twice as long and with a substantially longer hospital stay. Direct comparisons between gram-negative and gram-positive shunt infections remain limited. Previous studies have also suggested that preventive strategies may influence the microbiological distribution of subsequent shunt infections, although the available findings are inconsistent. Konstantelias et al. reported a relative increase in gram-negative organisms among infections occurring in patients with antimicrobial shunt catheters, whereas Sedano et al. found no clear association between preventive practices and the type of organism subsequently isolated (11, 12). In the series by Arnell et al., intravenous treatment alone failed to sterilize the CSF in a subgroup of children, whereas culture clearance followed catheter externalization and the addition of intraventricular antibiotics; however, only five infections were gram-negative, preventing

organism-specific conclusions (13). Our findings therefore suggest that gram-negative involvement identifies infections associated with a more prolonged and demanding treatment course. However, because gram-negative infections were frequently polymicrobial, the independent contribution of gram-negative involvement could not be determined.

Positive blood or intravascular catheter-derived cultures were more frequent among patients with gram-negative infection. However, peripheral blood and catheter-derived samples could not be reliably distinguished in the retrospective records. Therefore, this finding cannot be interpreted as evidence of bacteremia and may instead reflect catheter colonization, contamination, or another concurrent source of infection.

Intraventricular antimicrobial therapy was administered to six patients, all with gram-negative infection; five received colistin and one received amikacin. Current guidelines recommend considering intraventricular therapy when the response to systemic treatment is inadequate, although the supporting evidence remains limited (8). Because intraventricular treatment was selectively used in gram-negative cases, its effect on CSF sterilization, recurrence, or hospital stay cannot be determined from our data.

Two-stage shunt replacement was the most commonly used surgical approach in our cohort, and nearly two-thirds of patients required temporary CSF diversion with an EVD or reservoir. This is consistent with the widely accepted practice of removing the infected hardware, providing temporary CSF diversion when necessary, administering pathogen-directed antimicrobial therapy, and subsequently implanting a new shunt after infection control (6, 14). In the adult series by Pelegrín et al., two-stage replacement achieved a CSF sterilization rate of 95% and had substantially lower treatment failure than one-stage replacement, while retention of the infected shunt was the only independent predictor of failure (5). In our cohort, however, the surgical strategy was not associated with subsequent recurrence. A prospective pediatric study by Simon et al. similarly found no independent association between surgical approach and reinfection risk (4). Therefore, our findings should not be taken to mean that the approaches are equivalent, as treatment selection was influenced by infection severity, microbiological findings, and the patient's ongoing need for CSF diversion.

Recurrent infection was documented in 17 of the 35 evaluable patients (48.6%), exceeding the

reinfection rates reported in previous pediatric cohorts: 14.8% in Simon et al. (15), 26% in Kestle et al. (16), and 16.3% in Simon et al. (4). Differences in age composition, referral setting, and follow-up duration may partly explain this finding. Wound swab culture positivity was the only variable associated with recurrence and may reflect more extensive involvement of the surgical wound or shunt tract. However, previous pediatric studies did not identify the initial microorganism or surgical treatment strategy as significant predictors of repeat infection (4, 17). Because this was an unadjusted analysis in a small cohort, the association requires confirmation.

Initial CSF protein concentration was not significantly associated with time to CSF sterilization or subsequent recurrence. Although elevated CSF protein before shunt placement or reinsertion has been associated with infection or reinfection in previous pediatric cohorts (18, 19), the timing of measurement differed from that in our study. Moreover, CSF cytochemical findings are highly variable and may not reliably distinguish the type of causative microorganism (4, 8, 20).

This study has several limitations. Its retrospective, single-center design and small sample size limited the statistical power and precluded reliable multivariable analysis. The cohort included both pediatric and adult patients, introducing clinical heterogeneity in underlying disease, treatment decisions, and follow-up. Some laboratory variables were unavailable for all patients, and peripheral blood cultures could not always be distinguished from samples obtained through intravascular catheters. In addition, the exact timing and microbiological characteristics of recurrent episodes were not consistently documented; therefore, relapse could not be reliably differentiated from reinfection, and recurrence could not be analyzed using time-to-event methods. Finally, surgical and antimicrobial treatments were selected according to clinical judgment, making the comparisons susceptible to confounding by indication.

In conclusion, staphylococci remained the predominant pathogens in VP shunt infections, although gram-negative and polymicrobial infections were also common. Gram-negative involvement was associated with delayed CSF sterilization and longer hospitalization. Recurrent infection occurred frequently, and wound swab culture positivity emerged as a potential marker of recurrence. Larger prospective studies are needed to confirm predictors of recurrence and clarify the optimal surgical and antimicrobial management.

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