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ORIGINAL ARTICLE

Ventriculoperitoneal Shunt Infection in Severely Disabled Adults: Association of a Modified Tracheostomy Focused Surgical Protocol with Reduced Infection Rates

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Abstract

BACKGROUND: Ventriculoperitoneal shunt (VPS) infection is a serious complication following shunt placement for hydrocephalus, particularly in patients with severe neurological impairment who require prolonged rehabilitation and invasive supportive devices such as tracheostomy and nasogastric feeding.
OBJECTIVE: This study aimed to determine the incidence of VPS infection in a severely disabled adult hydrocephalus cohort and to evaluate the association between a modified surgical technique and VPS infection, alongside other potential risk factors. The findings were intended to guide the refinement and ongoing optimization of our department's standardized surgical protocols to further reduce infection risk.
METHODS: We conducted a single centre retrospective before–after cohort study of 284 adults undergoing first time VPS between 2022 and 2024, comparing patients treated with the conventional technique (n = 168) and those treated after implementation of a modified, tracheostomy focused surgical protocol (n = 116). All patients were followed for 12 months, and predefined clinical, laboratory, and procedural variables were extracted from medical records.
RESULTS: A total of 284 patients with hydrocephalus who were followed up for at least one year were included in the study. VPS infection occurred in 35 of 284 patients (12.3%), with 29 of 35 infections (82.8%) arising within 3 weeks of surgery. Infection rates were 17.9% (30/168) in the conventional group and 4.3% (5/116) in the modified protocol group (absolute risk reduction 13.6%), corresponding to approximately one infection prevented for every 7–8 patients treated with the modified technique ($\chi^2 = 11.654$, $p < 0.001$). No other predefined patient related or shunt related factors showed a significant association with infection.

CONCLUSION: In this severely disabled adult cohort, VPS infection was common, and most infections occurred within 3 weeks of surgery. Adoption of the modified, tracheostomy focused surgical protocol was associated with a substantially lower observed incidence of VPS infection, although residual confounding cannot be excluded in this retrospective before–after design. Prospective studies are needed to confirm the effect and define optimal preventive strategies for high risk VPS patients.

INTRODUCTION

Hydrocephalus in adults is generally classified as either spontaneous or secondary. Spontaneous hydrocephalus results from congenital abnormalities or impaired cerebrospinal fluid (CSF) absorption (Abubacker, 2001). In contrast, secondary hydrocephalus typically arises from brain injury, cerebral hemorrhage, tumors, or infections, leading to ventricular or subarachnoid space due to abnormal CSF accumulation. Among these causes, subdural, subarachnoid, and intraventricular hemorrhage are the primary contributors to secondary hydrocephalus. The incidence of post-traumatic hydrocephalus ranges from 12% to 36% in patients with brain injury, depending on injury severity, and is particularly common among those undergoing decompressive craniectomy (Linnemann, 2014; Goldschmidt, 2020). Moreover, 51%–89% of patients with intraventricular hemorrhage develop hydrocephalus (Chen *et al.* 2017).

Ventriculoperitoneal shunt (VPS) remains the mainstay treatment for hydrocephalus. However, postoperative shunt infection (SI) is a serious and relatively frequent complication, occurring in 2% - 27% of cases (Kestle *et al.* 2011). SI significantly increases mortality, disability, and healthcare costs, and may lead to long-term sequelae such as cognitive impairment and epilepsy (Simon *et al.* 2009). To minimize the infection risk, various factors—including patient characteristics (e.g., sex, age, and preoperative physical condition), surgical techniques, and perioperative management—must be carefully considered. Identifying and addressing these risk factors are critical for preventing SI and improving patient prognosis. Therefore, a comprehensive understanding of the risk factors, etiological features, and preventive strategies for SI following VPS is of great clinical significance.

The primary objective of this study was to determine the incidence and timing of VPS infection in a severely disabled adult hydrocephalus cohort and to identify relevant risk factors, including the presence of tracheostomy and other patient related variables. In addition, we aimed to evaluate the association between a modified, tracheostomy focused surgical protocol and VPS infection, with the goal of informing department wide preventive strategies.

METHODS

Study Design

We conducted a single centre retrospective before–after cohort study of 284 adults with spontaneous or secondary hydrocephalus who underwent first time VPS placement between January 2022 and December 2024 in our neurosurgery department. Patients operated before implementation of the modified protocol (January 2022–June 2023; n = 168) formed the conventional technique group, and those operated after implementation (July 2023–December 2024; n = 116) formed the modified protocol group. All patients were followed for 12 months after surgery. At the time of VPS placement, most patients were severely disabled (ADL score 0 in 235/284, 82.7%), and 154/284 (54.2%) had a tracheostomy. VPS procedures were performed by neurosurgeons of the medical institution using shunt systems manufactured by Medtronic (USA) and B. Braun (Germany).

Patients were classified as follows according to the etiology of hydrocephalus: intracranial hemorrhage, post-traumatic, and other (spontaneous hydrocephalus, cerebral infarction, arteriovenous malformations, aneurysms, meningiomas, intracranial lymphomas, ischemic-hypoxic encephalopathy, and viral encephalitis). The intracranial hemorrhage subgroup included patients with spontaneous intracerebral hemorrhage, subdural hemorrhage, and intraventricular hemorrhage. Before the diversion surgery, patients were examined by blood routine, urine routine, chest CT, head MR enhanced scan, and lumbar puncture cerebrospinal fluid examination to exclude the possibility of occult infection.

Diagnostic Criteria for VPS Infection

The diagnosis of postoperative VPS infection was established based on standardized criteria for central

Tab. 1. Infection rates by hydrocephalus etiology

Etiology	Cases (%)	Intracranial infection		Chi-square	*p*
		Yes	No		
Traumatic brain injury	110(38.7%)	15(13.6%)	95(86.4%)	3.386	0.184
Cerebral hemorrhage	94(33%)	7(7.4%)	87(92.6%)		
Others	80(28.1%)	13(16.3%)	67(83.8%)		

Infection frequency and percentage are shown for traumatic brain injury, cerebral hemorrhage, and other etiologies in 284 adults undergoing first time VPS placement; chi square statistics and *p* values compare infection rates across etiologic groups.

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Tab. 2. Patient related factors and VPS infection

Variables	Cases (%)	Intracranial infection		Chi-square	*p*
		Yes	No		
Sex					
Male	187(65.8%)	24(12.8%)	163(87.2%)	0.132	0.716
Female	97(34.1%)	11(11.3%)	86(88.7%)		
Age					
≥ 60 years	81(28.5%)	8(9.8%)	73(90.2%)	0.628	0.428
< 60 years	203(71.5%)	27(13.3%)	176(86.7%)		
ADL score					
0	235(82.7%)	30(12.7%)	205(87.2%)	0.246	0.62
> 0	49(17.3%)	5(10.2%)	44(90.8%)		
Total protein (g/l)					
≥ 65	141(49.6%)	17(12%)	124(88%)	0.019	0.892
< 65	143(50.4%)	18(12.5%)	125(87.5%)		
Albumin (g/l)					
≥ 40	89(31.3%)	13(14.6%)	76(85.4%)	0.625	0.429
< 40	195(68.7%)	22(11.2%)	173(78%)		
Tracheostomy					
Yes	154(54.2%)	19(12.3%)	135(87.7%)	0.000	0.994
No	130(45.8%)	16(12.3%)	114(87.7%)		
Puncture site					
Frontal eminence	66(23.2%)	6(9%)	60(94%)	0.832	0.362
Occipital horns	218(76.8%)	29(13.3%)	189(86.7%)		
Shunts					
Medtronic	257(90.4%)	33(12.8%)	224(87.2%)	0.667	0.414
B. Braun	27(9.6%)	2(7.4%)	25(92.6%)		

Association between patient related factors and ventriculoperitoneal shunt infection.
Infection frequency and percentage are presented according to sex, age group, ADL score, and preoperative total protein and albumin levels in 284 adults undergoing first time VPS placement, with chi square statistics and *p* values for each factor.
Note: ADL refers to activities of daily living (Brathel Index Rating Criteria)

nervous system infections. The diagnostic criteria were as follows: the presence of at least two of the following symptoms after VPS including (a) persistent fever (body temperature > 38.5 °C) accompanied by signs of meningeal irritation; (b) cerebrospinal fluid (CSF) analysis showed a cloudy appearance, and the number of white blood cells exceeded 10×10^6 L^{-1}; (c) positive findings on CSF Gram staining or culture; and (d) CSF biochemical abnormalities, including reduced glucose and chloride levels.

Modified Surgical Technique

To further reduce the infection rate associated with VPS surgery, a modified surgical technique was introduced based on the conventional approach. After identifying the potential risk of contamination related to tracheostomy on January 19, 2022, our medical team took the lead in implementing this improvement. In the modified procedure, the tracheotomy site is temporarily sutured and closed during VPS surgery, and general anesthesia is administered through oral endotracheal intubation (whereas previously, ventilation was delivered via the tracheotomy). After skull drilling, but before ventricular catheter placement and shunt connection, a 3% iodophor swab is used to seal the incision margins, and the shunt system is immersed briefly in sterile normal saline to limit air exposure. This bundle was designed to reduce intraoperative contamination from respiratory and skin flora, particularly in patients with tracheostomy. Other medical groups within the department continued to use the original technique and planned to adopt the unified modified protocol by the end of 2023.

Observation Indicators

Clinical data were extracted from patients' medical records and included initial assessments, daily progress

Tab. 3. Disease and shunt related factors and VPS infection

Types of hydrocephalus	Cases (%)	Intracranial infection		Chi-square	*p*
		Yes	No		
Secondary hydrocephalus	278(97.8%)	35(12.5%)	243(87.5%)	0.834	0.361
Spontaneous hydrocephalus	6(2.2%)	0(0%)	6(100%)		

Association between disease and shunt related factors and ventriculoperitoneal shunt infection.
Infection frequency and percentage are shown by hydrocephalus type, tracheostomy status at the time of VPS, ventricular puncture site, and shunt type, with chi square statistics and *p* values for comparisons.

notes, surgical reports, laboratory and imaging results, and follow-up information. Analyzed variables encompassed patient demographics (age, sex), potential risk factors, hydrocephalus etiology and type, medical and surgical history, clinical presentation, laboratory and imaging findings, management strategies, outcomes, and follow-up duration. Access to the data was limited to authorized personnel involved in data processing to ensure data confidentiality.

Statistical Analysis

Statistical analysis was performed using SPSS 22.0 (IBM Corp., Armonk, NY, USA). The normality of all variables was assessed prior to analysis. Continuous variables were expressed as the mean ± standard deviation (SD), while categorical variables were presented as percentages. Comparisons of categorical variables were conducted using the chi-square test, with statistical significance set at $p < 0.05$.

RESULTS

Analysis of Clinical Characteristics and Etiological Data

A total of 284 patients underwent VPS and were followed for at least 1 year. Cases with missing follow-up data or those not meeting the study criteria were excluded from statistical analysis.

The two most common causes of hydrocephalus were traumatic brain injury (n = 110, 38.7%) and intracerebral hemorrhage (n = 94, 33%). Other etiologies (n = 80, 28.1%) included spontaneous hydrocephalus (n = 6, 2.1%), cerebral infarction (n = 16, 5.6%), arteriovenous malformations (n = 7, 2.7%), aneurysms (n = 44, 15.4%), meningioma (n = 4, 1.4%), intracranial lymphoma (n = 1, 0.3%), ischemic hypoxic encephalopathy (n = 1, 0.3%), and viral encephalitis (n = 1, 0.3%).

There was no statistically significant difference in VPS infection rates among patients with hydrocephalus of different etiologies ($p = .184$; Table 1). VPS infection occurred in 35 patients (12.3%) (Figure 1A), distributed by etiology as follows: aneurysms (n = 8), cerebral hemorrhage (n = 7), traumatic brain injury (n = 15), cerebral infarction (n = 3), and arteriovenous malformations (n = 2). After treatment, 34 patients (97.1%) recovered, while one (2.9%) died due to cerebral herniation following recurrent intracranial hemorrhage.

Risk Factors Associated with VPS Infection

Analysis of predefined factors associated with VPS infection revealed no significant difference in infection rates between male (n = 187, 65.8%) and female (n = 97, 34.1%) patients ($p = 0.716$). The mean age of patients was 51.8 ± 15.03 years (range: 5–78 years), and there was no significant difference in infection rates between patients aged ≥ 60 years and those < 60 years ($p = 0.428$). Similarly, no significant difference was observed between patients who were completely bedridden (ADL (activity of daily living) score = 0) and those with partial functional ability (ADL score > 0) ($p = 0.62$).

Preoperative laboratory values, including total protein and albumin, were not significantly associated with infection ($p = 0.892$ and $p = 0.429$, respectively). Other factors, such as tracheostomy status ($p = 0.994$), ventricular puncture site ($p = 0.362$), and shunt type ($p = 0.414$), also showed no significant effect (Table 2). Furthermore, VPS infection rate did not differ significantly among patients with different types of hydrocephalus ($p = 0.361$; Table 3).

Modified Surgical Technique and VPS Infection Incidence

The conventional technique group comprised patients operated on before the department-wide adoption

Tab. 4. VPS infection before and after protocol modification

Surgical approach	Cases	Intracranial infection		Chi-square	*p*
		Yes	No		
Conventional method	168	30(17.9%)	138(82.1%)	11.654	<0.001
Modified surgical technique	116	5(4.3%)	111(95.7%)		

Ventriculoperitoneal shunt infection incidence before and after implementation of the modified surgical protocol.
Numbers and percentages of VPS infections are reported for patients operated with the conventional technique and for those treated after introduction of the modified, tracheostomy focused protocol, together with chi square statistic and *p* value

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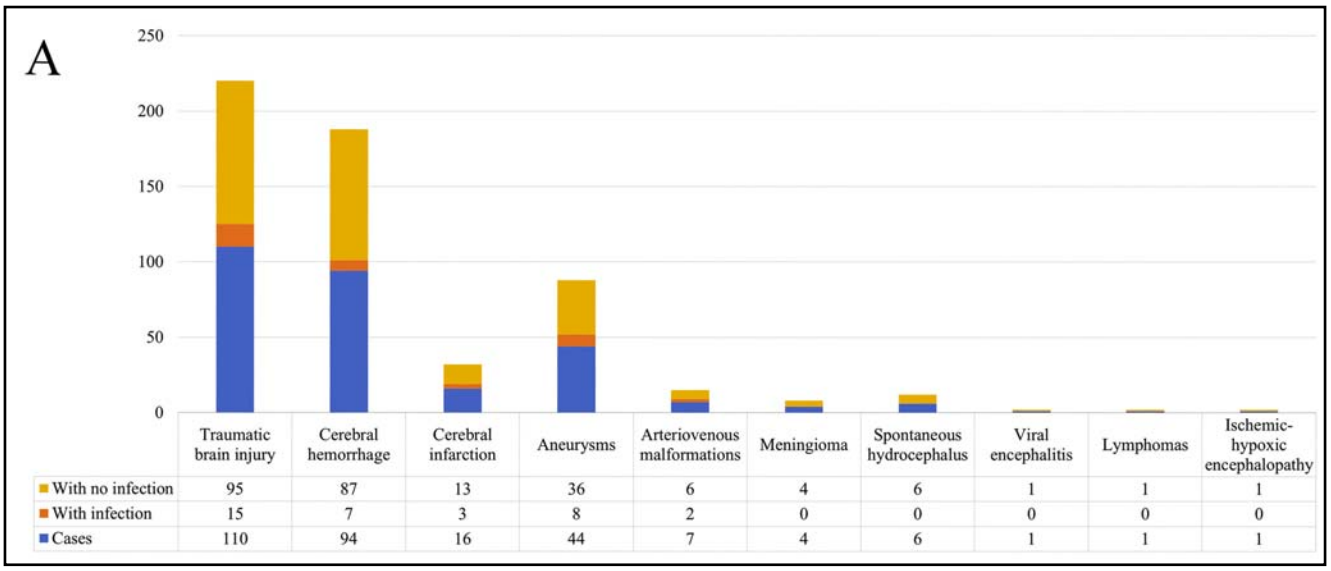

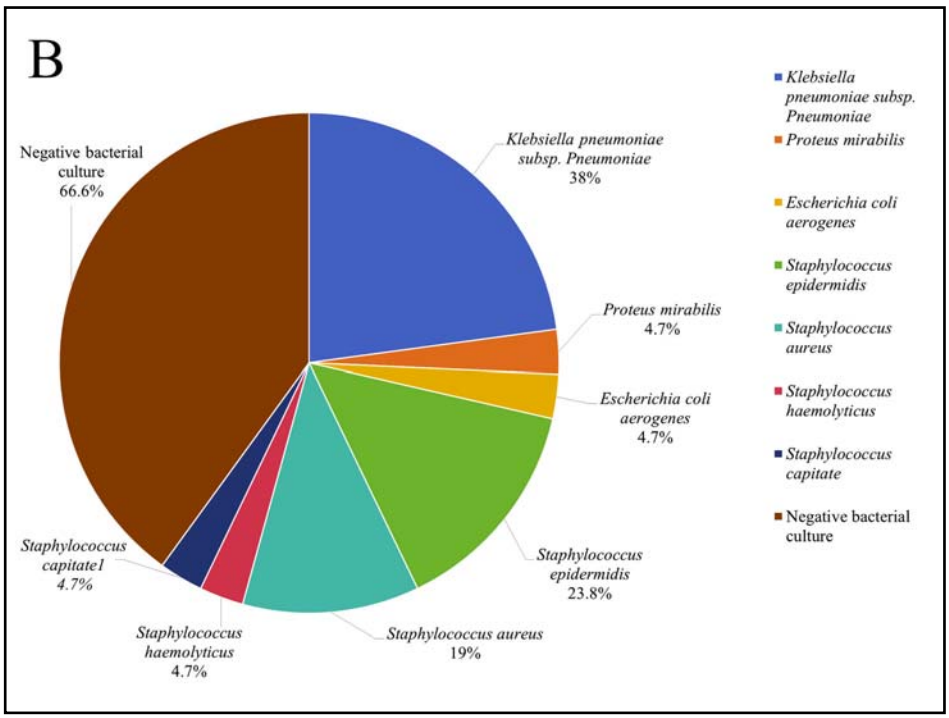

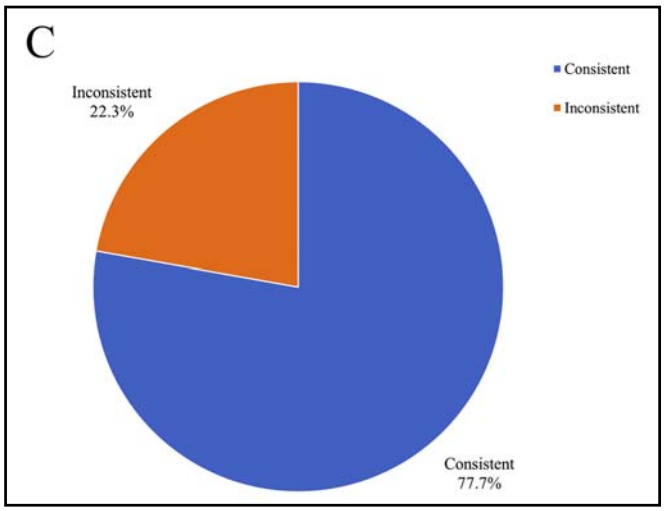

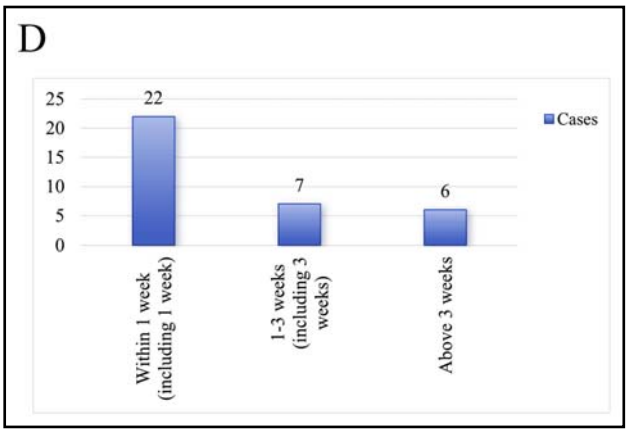

Fig. 1. Ventriculoperitoneal shunt infection patterns
(A) Postoperative VPS infection rates according to hydrocephalus etiology in 284 adults undergoing first time shunt placement.
(B) Distribution of pathogens isolated from cerebrospinal fluid cultures in 21 culture positive VPS infections.
(C) Concordance between bacterial species isolated from CSF and sputum in tracheostomized patients with culture positive VPS infection.
(D) Time interval from VPS surgery to onset of infection among the 35 patients who developed VPS infection.

of the modified protocol (January 2022–June 2023; n = 168), while the modified technique group comprised patients operated on thereafter (July 2023–December 2024; n = 116). Overall, VPS infection occurred in 30 of 168 patients (17.9%) treated with the conventional technique and 5 of 116 patients (4.3%) treated after implementation of the modified protocol, representing a 13.6 percentage point absolute reduction in infection rate ($\chi^2 = 11.654$, $p < 0.001$; Table 4).

CSF Analysis and Microbiological Findings in Patients with VPS Infection

Among the 35 patients who developed VPS infection, 21 (60.0%) had positive CSF cultures. Gram negative organisms accounted for 10 of 21 culture positive infections (47.6%) and gram positive organisms for 11 (52.4%). The most frequent single pathogen was Klebsiella pneumoniae subsp. pneumoniae (8/21, 38.1%), followed by Staphylococcus epidermidis (5/21, 23.8%) and Staphylococcus aureus (4/21, 19.0%) (Figure 1B). Among patients with tracheostomy, 9 had positive CSF cultures, and in 7 of these 9 cases (77.8%) the same bacterial species was isolated from both CSF and sputum (Figure 1C).

Time Interval Between Surgery and Onset of VPS Infection

Of the 35 patients with VPS infection (12.3% of the cohort), 22 (62.9%) developed infection within 1 week after surgery, 7 (20.0%) between 1 and 3 weeks, and 6 (17.1%) beyond 3 weeks, so that 29 of 35 infections (82.8%) occurred during the first 3 postoperative weeks (Figure 1D).

DISCUSSION

In this single centre retrospective before–after cohort of 284 adults undergoing first time VPS, the overall VPS infection rate was 12.3%, and 82.8% of infections occurred within 3 weeks of surgery; no VPS infection related deaths were observed during 12 month follow up. Infection rates were substantially lower after implementation of the modified, tracheostomy focused surgical protocol (17.9% vs 4.3%; absolute risk reduction 13.6%), whereas no significant association with infection was observed for age, sex, etiology, ADL score, tracheostomy status at the time of VPS, total protein, albumin, ventricular puncture site, shunt type, or hydrocephalus type. The most common pathogens were Klebsiella pneumoniae subsp. pneumoniae, Staphylococcus epidermidis, and Staphylococcus aureus, and in tracheostomized patients, 77.8% of culture positive cases showed concordant bacterial species in CSF and sputum

The overall VPS infection rate of 12.3% lies toward the higher end of the 2–27% range reported in previous series. This likely reflects the very high proportion of bedridden patients (82.7%) and tracheostomy use (54.2%) in our rehabilitation-based cohort, which differs from many acute neurosurgical populations. However, variations in the timing of infection onset compared to other studies may reflect differences in overall infection estimates, sample sizes, study protocols, and patient populations. Differences in infection mechanisms may also contribute to these discrepancies.

Mortality and disability rates associated with post-VPS placements have been infrequently reported, likely due to the difficulty of distinguishing these outcomes from those of the underlying disease. In 1996, Jamjoom *et al.* (1996) reported one death due to a brain abscess among 12 VPS patients with infection, corresponding to a mortality rate of 8.3%, while severe disability was noted in 6 patients (50%). Wu *et al.* (2015) reported an 82% survival rate following shunt removal and intravenous antibiotic therapy, noting that most bacterial isolates were susceptible to carbapenems and vancomycin, with an average hospital stay of 47 days. In the present study, no deaths due to VPS infection were observed, which may be attributed to the use of postoperative antibiotics, improvements in infection management, and increased use of intrathecal antimicrobial therapy.

Identifying risk factors for infections following VPS placements is crucial in clinical practice, as a thorough understanding of these factors can inform strategies for infection prevention. Risk factors are generally classified into three categories: patient-related factors (e.g., sex, age, baseline functional status, comorbidities, immune status, and shunt duration), surgical factors (e.g., surgeon experience, use of prophylactic antibiotics, type of valve or catheter, and number of personnel involved), and postoperative/perioperative factors (e.g., postoperative antibiotic use, wound care, and overall postoperative management).

In this study, a comprehensive analysis of patient-related factors was conducted, focusing on the impact of preoperative nutritional status on infection risk. Preoperative total protein and albumin levels, which serve as indirect markers of immune function, were evaluated alongside ADL scores, tracheostomy status, and ventricular puncture sites. Notably, there were no significant differences in VPS infection incidence across patient groups stratified by etiology, sex, age, functional status, preoperative nutritional parameters, tracheotomy status, ventricular puncture sites, shunt type, or hydrocephalus type. These findings are consistent with previous studies: Alkosha *et al.* (2022) reported that the patient's demographics, hydrocephalus etiology, shunt-related factors, and preoperative antibiotic type were not significantly associated with VPS infection, while Rozzelle *et al.* (2008) found no significant difference in infection rates between hydrocephalus secondary to intracerebral hemorrhage and spontaneous hydrocephalus, or between different shunt types.

In a study of 1,570 patients undergoing hydrocephalus surgery, Erps *et al.* (2018) identified neoplastic

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hydrocephalus as a protective factor against VPS infection. Yang *et al.* (2020) examined 490 VPS patients and found no significant association between hydrocephalus etiology and VPS infection, consistent with the present study. However, they also reported higher infections among patients over 60 years of age, those with diabetes, and bedridden individuals—findings that differ from those of the current study.

In a multicenter controlled study, Simon *et al.* (2014) identified that the presence of an indwelling gastric tube, advanced age, and prior neurosurgery as independent risk factors for VPS infection. The present study was conducted in a rehabilitation research center where most patients are bedridden, require nasogastric feeding, and have severe illness, which may explain some discrepancies with prior studies. Nonetheless, consistent with the current results, other studies have reported no significant association between shunt type and infection risk in VPS placement (Lane *et al.* 2014; Mallucci *et al.* 2020).

VPS placement involves the implantation of a foreign body, making infections particularly challenging due to bacterial colonization on the shunt. In this study, all patients with positive CSF cultures underwent shunt removal. Once established, the shunt acts as a bacterial reservoir, promoting biofilm formation, which diminishes the effectiveness of antimicrobial therapy and increases the risk of recurrent infections. Alkosha *et al.* (2022) reported that two-thirds of infected shunts were colonized by *staphylococci* in a study of 392 VPS infection cases.

Clinical manifestations of VPS infections are variable. In this study, most patients initially presented with fever—sometimes up to 40 °C—with or without chills, altered consciousness, nausea, vomiting, and occasionally abdominal distension and diarrhea. Symptoms often vary by pathogen type: infections caused by gram-negative bacteria, such as *Escherichia coli*, may present with acute abdominal pain or sepsis, while infections caused by skin flora, such as *Staphylococcus epidermidis*, are generally milder. In contrast, erythema and edema around the shunt site are characteristic of *Staphylococcus aureus* infections (Stevens *et al.* 2012; Patel *et al.* 2012).

In the present study, the three most frequently identified pathogens were *Klebsiella pneumoniae* (38%), *Staphylococcus epidermidis* (23.8%), and *Staphylococcus aureus* (19%). In comparison, Raygor *et al.* (2020) reported *Staphylococcus epidermidis* as the predominant pathogen (52.6%) in 593 cases over 11 years, with *S. aureus* accounting for 18% to 48% of infections. Similarly, Simon *et al.* (2024) found that coagulase-negative staphylococci and S. aureus together represented nearly two-thirds of all post-VPS infections. Kumar *et al.* (2016) analyzed 1,186 VPS surgeries and, among 156 culture-positive samples, 79 (50.6%) were positive in the CSF (36 cases, 23.1%), shunt tubing (16 cases, 10.2%), or both (27 cases, 17.3%). The most common pathogens were *Staphylococcus aureus* (65 cases, 82.3%) and coagulase-negative *staphylococci* (22 cases, 25.3%) in the gram-positive group, and E. coli (17 cases, 21.5%) in the gram-negative group. Given that coagulase-negative staphylococci are common skin commensals, their involvement in VPS infections is likely attributable to skin colonization.

In contrast, in the present study, *Klebsiella pneumoniae* subsp. *pneumoniae* was the most frequently identified pathogen. This discrepancy may be due to the higher proportion of patients with tracheostomies in this cohort, as *Klebsiella pneumoniae* subsp. *pneumoniae* is commonly found in sputum cultures. Among the nine tracheostomy patients with positive CSF cultures, seven (77.7%) had identical bacterial isolates in both CSF and sputum.

Once a VPS infection is diagnosed, prompt administration of appropriate intravenous antibiotics is essential. In the absence of bacterial culture and susceptibility results, empirical therapy with meropenem and vancomycin, as recommended by Guidelines for the Clinical Use of Antimicrobial Agents (Document No. 43[2015] of the National Health Commission), provides broad-spectrum coverage (General Office NH and FPC *et al.*). When culture and susceptibility results become available, therapy should be adjusted accordingly. Intrathecal antibiotic administration and external ventricular drainage are also effective adjuncts in infection management. Short-term glucocorticoid therapy may be considered to control inflammation and improve symptoms, provided adequate antibiotic coverage is ensured.

In this study, no significant correlation was observed between patient-related factors and VPS infection. Notably, in patients with tracheostomy, the concordance between sputum and CSF cultures reached 77%, highlighting the potential role of respiratory colonization. To minimize intraoperative contamination, we implemented a modified surgical technique. Patients operated after this change had a lower observed incidence of VPS infection than those treated earlier (17.9% with the conventional technique vs 4.3% after implementation; $p < 0.001$). Because the groups were separated in time and the study was not randomized, these findings should be interpreted as an association rather than definitive proof of causality. Between 2023 and 2024, two surgical teams adopted this technique, which included: removal of the tracheostomy cannula after induction of general anesthesia, oral intubation, temporary suturing and closure of the tracheostomy wound, immersion of the shunt in saline for 10 minutes prior to puncture to avoid air exposure, and placement of 3% iodophor tampons around the head incision during ventricular puncture and shunt system connection.

Regarding antibiotic prophylaxis, VL *et al.* (2022) reported a significant reduction in shunt infection rates: 2.24% (53/2,362) in the topical antibiotic group versus 5.24% (145/2,764) in the control group ($p = 0.008$). Subgroup analyses revealed no significant differences

among the specific antibiotics used, reinforcing the importance of minimizing intraoperative contamination in preventing VPS infection.

Among surgical factors, Simon *et al.* (2019) emphasized measures such as limiting personnel movement in the operating room, using haircuts instead of shaving, standardized surgical site preparation, strict hand hygiene, and double-gloving—all shown to reduce infection rates. Pillai (2021) highlighted the importance of preoperative planning, standardized shunt surgery protocols, meticulous surgical techniques, gentle tissue handling, and minimizing operative time to reduce VPS-related complications. Walek *et al.* (2023) noted that contamination of VPS tubing with skin flora, particularly coagulase-negative staphylococci, is a major cause of infection and shunt failure, recommending the removal or replacement of outer surgical gloves immediately before VPS implantation as an infection control measure.

These findings underscore the critical role of intraoperative contamination in surgical site infections and support the rationale for the significant reduction in infection rates observed following the modified surgical technique in this study. However, bacterial colonization may not be confined to the intraoperative period but could extend throughout the postoperative wound healing phase. Thompson *et al.* (2007) and Haines (2007) suggested that the operating room environment may be a more important source of infectious organisms than the patient's skin. Therefore, while the modified surgical technique appears beneficial, its precise impact requires further investigation through prospective, randomized controlled trials.

This study has several limitations. First, it was a single centre retrospective analysis, and the findings may not be generalizable to other settings. Second, the cohort was disproportionately severely ill: 235 of 284 patients (82.7%) were completely bedridden (ADL = 0) and 154 (54.2%) had tracheostomies at the time of VPS, which may have independently increased infection risk and differed between technique groups in ways not fully controlled for. Third, the sequential, non randomized adoption of the modified protocol introduces potential temporal confounding, because secular changes in overall infection control practices between 2022 and 2024 cannot be excluded as contributors to the observed reduction in infection incidence.

CONCLUSION

In this severely disabled adult cohort, VPS infection was a common complication following first time VPS placement, and most infections occurred within 3 weeks of surgery. *Klebsiella pneumoniae* subsp. *pneumoniae*, *Staphylococcus epidermidis*, and *Staphylococcus aureus* were the predominant pathogens, and in tracheostomized patients, concordant bacterial species were frequently isolated from CSF and sputum. We did not detect significant associations between VPS infection and predefined patient related or shunt related factors, but within the limits of this single centre retrospective before–after design, adoption of the modified, tracheostomy focused surgical protocol was associated with a substantially lower observed infection incidence. Prospective, ideally randomized studies are needed to confirm these findings and to clarify the impact of tracheostomy management on VPS infection risk.

DECLARATIONS

Ethics approval and consent to participate

This study was conducted with approval from the Ethics Committee of Beijing Bo'Ai Hospital. This study was conducted in accordance with the declaration of Helsinki. Informed consent was waived due to the retrospective nature of the study, which involved the analysis of existing clinical data with no direct patient contact or intervention.

Consent for publication

Not applicable.

Conflict of interests

The authors declare that they have no conflict of interests.

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No external funding was received to conduct this study.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Authors' contributions

Jian-Jun Wang: Conceptualization, Data curation, Formal Analysis, Software, Writing – original draft.
Yu Wang: Data curation, Formal Analysis.
Wei Sun: Conceptualization, Writing – review & editing.
Shuang Chen: Formal Analysis, Software.
Jian-Yun Zhou: Conceptualization, Writing – original draft, Writing – review & editing.
All authors read and approved the final draft.

REFERENCES

1 Abubacker M, Bosma JJ, Mallucci CL, May PL (2001). Spontaneous resolution of acute obstructive hydrocephalus in the neonate. Childs Nerv Syst. **17**(3): 182–184. doi: 10.1007/s003810000386.
2 Alkosha HM, Mohammed MIR, El Shokhaiby UM, Amen MM (2022). A proposed protective protocol predicting reduction of shunt infection. World Neurosurg. **164**: e1049–e1057. doi: 10.1016/j.wneu.2022.05.090.
3 Chen Q, Feng Z, Tan Q, Guo J, Tang J, Tan L, et al. (2017). Post-hemorrhagic hydrocephalus: recent advances and new therapeutic insights. J Neurol Sci. **375**: 220–230. doi: 10.1016/j.jns.2017.01.072.

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4 Erps A, Roth J, Constantini S, Lerner-Geva L, Grisaru-Soen G (2018). Risk factors and epidemiology of pediatric ventriculoperitoneal shunt infection. Pediatr Int. **60**(12): 1056–1061. doi: 10.1111/ped.13709.

5 General Office of the National Health and Family Planning Commission, Office of the State Administration of Traditional Chinese Medicine, Bureau of Medicines and Medical Equipment, Health Department of the General Logistics Department of the People's Liberation Army (2015). Guidelines for the clinical use of antimicrobial agents (2015 edition). National Health Commission of the People's Republic of China.

6 Goldschmidt E, Deng H, Puccio AM, Okonkwo DO (2020). Post-traumatic hydrocephalus following decompressive hemicraniectomy: incidence and risk factors in a prospective cohort of severe TBI patients. J Clin Neurosci. **73**: 85–88. doi: 10.1016/j.jocn.2020.01.027.

7 Haines SJ (2007). Shunt infection. J Neurosurg. **106**(1 Suppl): 13–14. doi: 10.3171/ped.2007.106.1.13.

8 Jamjoom AB, Mohammed AA, Al-Boukai A, Jamjoom ZA, Rahman N, Jamjoom HT (1996). Multiloculated hydrocephalus related to cerebrospinal fluid shunt infection. Acta Neurochir (Wien). **138**(6): 714–719. doi: 10.1007/BF01411477.

9 Kestle JR, Riva-Cambrin J, Wellons JC 3rd, Kulkarni AV, Whitehead WE, Walker ML, et al. (2011). A standardized protocol to reduce cerebrospinal fluid shunt infection: the Hydrocephalus Clinical Research Network Quality Improvement Initiative. J Neurosurg Pediatr. **8**(1): 22–29. doi: 10.3171/2011.4.PEsDS10551.

10 Kumar V, Shah AS, Singh D, Loomba PS, Singh H, Jagetia A (2016). Ventriculoperitoneal shunt tube infection and changing pattern of antibiotic sensitivity in neurosurgery practice: alarming trends. Neurol India. **64**(4): 671–676. doi: 10.4103/0028-3886.185408.

11 Lane JD, Mugamba J, Ssenyonga P, Warf BC (2014). Effectiveness of the Bactiseal Universal Shunt for reducing shunt infection in a sub-Saharan African context: a retrospective cohort study in 160 Ugandan children. J Neurosurg Pediatr. **13**(2): 140–144. doi: 10.3171/2013.11.PEDS13394.

12 Linnemann M, Tibæk M, Kammersgaard LP (2014). Hydrocephalus during rehabilitation following severe TBI: relation to recovery, outcome, and length of stay. NeuroRehabilitation. **35**(4): 755–761. doi: 10.3233/NRE-141160.

13 Mallucci CL, Jenkinson MD, Conroy EJ, Hartley JC, Brown M, Moitt T, et al. (2020). Silver-impregnated, antibiotic-impregnated or non-impregnated ventriculoperitoneal shunts to prevent shunt infection: the BASICS three-arm RCT. Health Technol Assess. **24**(17): 1–114. doi: 10.3310/hta24170.

14 Patel C, Chaudhuri NR, Gaur S (2012). Group A streptococcus ventriculoperitoneal shunt infection in a child. Pediatr Infect Dis J. **31**(6): 660. doi: 10.1097/INF.0b013e31824c04a5.

15 Pillai SV (2021). Techniques and nuances in ventriculoperitoneal shunt surgery. Neurol India. **69**(Suppl): S471–S475. doi: 10.4103/0028-3886.332261.

16 Raygor KP, Oh T, Hwang JY, Phelps RRL, Ghoussaini K, Wong P, et al. (2020). Ventriculoperitoneal shunt infection rates using a standard surgical technique, including topical and intraventricular vancomycin: the Children's Hospital Oakland experience. J Neurosurg Pediatr. **26**(5): 504–512. doi: 10.3171/2020.4.PEDS209.

17 Rozzelle CJ, Leonardo J, Li V (2008). Antimicrobial suture wound closure for cerebrospinal fluid shunt surgery: a prospective, double-blinded, randomized controlled trial. J Neurosurg Pediatr. **2**(2): 111–117. doi: 10.3171/PED/2008/2/8/111.

18 Simon TD, Butler J, Whitlock KB, Browd SR, Holubkov R, Kestle JR, et al. (2014). Risk factors for first cerebrospinal fluid shunt infection: findings from a multi-center prospective cohort study. J Pediatr. **164**(6): 1462–1468.e2. doi: 10.1016/j.jpeds.2014.02.013.

19 Simon TD, Hall M, Riva-Cambrin J, Albert JE, Jeffries HE, Lafleur B, et al. (2009). Infection rates following initial cerebrospinal fluid shunt placement across pediatric hospitals in the United States. J Neurosurg Pediatr. **4**(2): 156–165. doi: 10.3171/2009.3.PEDS08215.

20 Simon TD, Schaffzin JK, Podkovik S, Hodor P (2024). Cerebrospinal fluid shunt infections. Infect Dis Clin North Am. **38**(4): 757–775. doi: 10.1016/j.idc.2024.07.008.

21 Simon TD, Schaffzin JK, Stevenson CB, Willebrand K, Parsek M, Hoffman LR (2019). Cerebrospinal fluid shunt infection: emerging paradigms in pathogenesis that affect prevention and treatment. J Pediatr. **206**: 13–19. doi: 10.1016/j.jpeds.2018.11.026.

22 Stevens NT, Greene CM, O'Gara JP, Bayston R, Sattar MT, Farrell M, et al. (2012). Ventriculoperitoneal shunt-related infections caused by Staphylococcus epidermidis: pathogenesis and implications for treatment. Br J Neurosurg. **26**(6): 792–797. doi: 10.3109/02688697.2011.651514.

23 Thompson DN, Hartley JC, Hayward RD (2007). Shunt infection: is there a near-miss scenario? J Neurosurg. **106**(1 Suppl): 15–19. doi: 10.3171/ped.2007.106.1.15.

24 Vl G, Garg K, Tandon V, Borkar SA, Satyarthi GD, Singh M, et al. (2022). Effect of topical and intraventricular antibiotics used during ventriculoperitoneal shunt insertion on the rate of shunt infection: a meta-analysis. Acta Neurochir (Wien). **164**(7): 1793–1803. doi: 10.1007/s00701-022-05248-0.

25 Walek KW, Rajski M, Sastry RA, Mermel LA (2023). Reducing ventriculoperitoneal shunt infection with intraoperative glove removal. Infect Control Hosp Epidemiol. **44**(2): 234–237. doi: 10.1017/ice.2022.70.

26 Wu X, Liu Q, Jiang X, Zhang T (2015). Prevention options for ventriculoperitoneal shunt infections: a retrospective analysis during a five-year period. Int J Clin Exp Med. **8**(10): 19775–19780. PMID: 26770578.

27 Yang YN, Zhang J, Gu Z, Song YL (2020). The risk of intracranial infection in adults with hydrocephalus after ventriculoperitoneal shunt surgery: a retrospective study. Int Wound J. **17**(3): 722–728. doi: 10.1111/iwj.13331.