Predictors and microbiology of ventriculostomy-associated infections: A retrospective study of 216 patients

Junhyung Kim

Yonsei University Medical Center: Yonsei University Health System <https://orcid.org/0000-0002-8908-978X>

Jae Ho Kim

Gangnam Severance Hospital

Woosung Lee

Severance Health System: Yonsei University Health System

Hyun Jin Han

Severance Health System: Yonsei University Health System

Keun Young Park

Severance Health System: Yonsei University Health System

Joonho Chung

Severance Health System: Yonsei University Health System

Yong Bae Kim

Severance Health System: Yonsei University Health System

Jin Yang Joo

Gangnam Severance Hospital

Sang Kyu Park (✉ skparkns@gmail.com)

Yonsei University Medical Center: Yonsei University Health System <https://orcid.org/0000-0001-9231-0716>

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Abstract

BACKGROUND AND PURPOSE: Ventriculostomy-associated infection (VAI) is a serious complication of external ventricular drainage (EVD). Infection rates and risk factors are variable in the literature due to heterogeneity of EVD procedures and management. This study aimed to investigate the incidence of VAI and its associated factors in two institutions with identical EVD procedural and management protocols.

METHODS: The authors reviewed the medical records of patients older than 18 years who received EVD placements between January 2015 and December 2020 in two institutions under a single healthcare system.

RESULTS: A total of 216 patients with 328 catheters was included for analysis. Twenty-three VAIs were identified, a 10.6% VAI rate. VAI was associated with a shorter duration of first EVD (9.7 days vs. 11.8 days, $P = 0.018$), a longer total EVD duration (28.0 days vs. 16.1 days, $P < 0.001$), a longer procedural time (72 minutes vs. 40 minutes, $P < 0.001$), catheterization at non-Kocher's points (34.7% vs. 12.5%, $P = 0.010$), cerebrospinal fluid (CSF) leak (8.7% vs. 1.6%, $P = 0.030$), craniotomy (87.0% vs. 61.7%, $P = 0.020$), and other systemic infections (30.4% vs. 9.3%, $P = 0.012$). On multivariate analysis, the first EVD duration (OR = 0.095, $P < 0.001$), total EVD duration (OR 1.128, $P < 0.001$), EVD placement at non-Kocher's point (OR 4.545, $P = 0.012$), and other systemic infections (OR = 5.117, $P = 0.024$) were associated independently with VAI. There was no statistical difference in VAI rate between patients with or without prophylactic EVD exchange at 14 days (6.8% vs. 12.6%, $P = 0.247$).

CONCLUSIONS: Concomitant systemic infection and placement of an EVD catheter at a non-Kocher's point were independently associated with VAI. Prophylactic EVD exchange at 14 days did not lower VAI rate.

Background

External ventricular drainage (EVD) is an essential surgical procedure that allows rapid management of hydrocephalus, delivery of intrathecal drugs, and monitoring of intracranial pressure [1, 2]. It is a simple procedure that can be performed in various clinical settings by surgeons with diverse levels of experience. The most common complication is ventriculostomy-associated infection (VAI), occurring at an incidence rate from 10–45% or from 10–20% according to more recent studies [1–3]. As VAI is associated with poor prognosis and socio-economic burdens, many have investigated the risk factors for VAI and proper management of the draining catheter to prevent it [3–5]. A few proposed risk factors are prolonged duration of EVD placement, concurrent systemic infection, depressed cranial fracture, CSF leak, and intraventricular hemorrhage (IVH) [1]. However, some of the factors are controversial; for example, consensus has not been reached on whether duration of EVD placement, prophylactic EVD exchange, and cerebrospinal fluid (CSF) collection frequency influence the incidence of VAI [6–8]. The findings that EVD procedures and management strategies are heterogeneous and not standardized [9] might contribute to

the various and often contradicting results in the literature regarding the incidence of VAI and its risk factors.

The two institutions under the authors' healthcare system have a policy of prophylactic EVD catheter exchange every 10 to 14 days and routine CSF collection every three to five days for infection surveillance. EVD placements performed between January 2015 and December 2020 were reviewed retrospectively and evaluated for prevalence of VAI and its risk factors.

Methods

Ethical Issues

This study was approved by the institutional review board of the participating institutions. The need to obtain informed consent from patients was waived because of the retrospective study design. The study was performed under the guidelines outlined by the Declaration of Helsinki, and the manuscript followed the STROBE checklist.

Study Design and Patient Population

The medical records of patients older than 18 years who received EVD placements between January 2015 and December 2020 in two institutions were reviewed retrospectively. A total of 412 patients received EVD placements during the study period. Patients who met the following conditions were excluded: incomplete medical records, pre-existing central nervous system infections prior to initial EVD placement, initial EVD placed in other hospitals, presence of more than two EVD catheters at any period of time, and death within 14 days from EVD placement. Finally, 216 patients with 328 EVD catheterizations were included for analysis.

EVD Placement and Catheter Management

All EVD placements included in this study were performed in the operating room. Prophylactic antibiotics, usually first-generation cephalosporin unless the patient was already on other antibiotics, were administered in the operating room prior to skin incision. Skin preparation and surgical draping were performed in the usual manner. A standard EVD catheter without antibiotic-impregnation was used in all cases. When necessary, a navigation system was utilized to improve accuracy. The primary choice of EVD entry point was Kocher's point, and when necessary, EVDs were inserted at Paine's point, Frazier's point, or at the cisterna magna toward the third ventricle during craniotomy operations. Dressings were changed every two days at bedside, in an aseptic manner. A prophylactic catheter exchange was considered when an EVD catheter was expected to be maintained for longer than 14 days. When VAI was suspected, a catheter exchange was planned.

CSF Collection and Detection of CSF Infection

CSF samples were collected aseptically by surgeons or medical residents at the time of catheter insertion, routinely every three to five days, and at the time of catheter removal. The number of CSF collections other than those performed at the time of insertion or removal of EVD catheters was recorded for each

patient to reflect catheter manipulations. For practicality, VAI was diagnosed when positive CSF culture plus CSF protein > 40 g/dL and CSF glucose < 45 mg/dL were confirmed.

Clinical Data

Initial mental status at the time of EVD placement was dichotomized based on the Glasgow Coma Scale (GCS) as “good” if GCS was > 12 and “poor” if GCS was ≤ 12 . Other systemic infections included sepsis with positive blood culture and relevant clinical signs, pneumonia, and urinary tract infection diagnosed with radiologic, laboratory, and clinical evidence. A CSF leak while the EVD catheter was in place was documented when there was definite rhinorrhea or otorrhea following iatrogenic or traumatic skull base defect or CSF leak around the EVD insertion or lumbar drainage sites. Regarding the site of EVD catheterization, patients were dichotomized into having received EVD catheterizations only at Kocher’s point and non-Kocher’s point at least once. Timing of VAI was defined as the interval between initial EVD catheterization and CSF collection from which a positive culture was observed. Data regarding the number of EVD catheter exchanges and fever above 38.0°C during EVD catheterization for each patient were collected. Functional outcomes were evaluated as 90-day modified Rankin Scale (mRS) being “favorable” if mRS ≤ 2 , and “unfavorable” if mRS > 3. The primary endpoint was VAI detected from the CSF study, and secondary endpoint was 90-day ventriculo-peritoneal shunt (VPS) placement.

Statistical Analysis

Patients were divided into non-VAI and VAI groups, and data analysis was performed with IBM SPSS Statistics software Version 25.0 (IBM, Armonk, NY, USA). Univariate analysis was conducted using the Kruskal-Wallis test and Student t-tests for continuous variables and Fisher’s exact test and Chi-square test for categorical variables. Multiple logistic regression was performed, and results were presented with odds ratio (OR) and 95% confidence interval (CI), with a two-sided probability value of 0.05 for significance.

Results

Patient and procedure characteristics

This study analyzed a total of 216 patients, 328 catheters, and 3370 catheter-days. A patient received 1.52 catheterizations on average (maximum: five consecutive catheterizations) and maintained EVD catheters for a median duration of 15 days (interquartile range [IQR] 10–22). Hemorrhagic stroke was the most common underlying diagnosis for EVD placements (74.5%). The majority of patients received catheterizations only at Kocher’s point (85.2%), but 32 patients (14.8%) received EVD catheterizations in other sites at least once. IVH was present in 54.6% of the patients at the time of EVD placement. Prophylactic antibiotic agents were used in all patients. The patient and procedure characteristics are summarized in Table 1.

Table 1
Patients and procedure characteristics

Variables	Values
Age, mean (SD)	58.9 (15.0)
Sex, n (%)	
Male	92 (42.6)
Female	124 (57.4)
Comorbidities, n (%)	
Hypertension	117 (54.2)
Diabetes Mellitus	36 (16.7)
Diagnosis, n (%)	
Hemorrhage	161 (74.5)
Ischemia	12 (5.6)
Tumor	28 (13.0)
Trauma	11 (5.1)
Others	4 (1.9)
Initial mental status†, n (%)	
Good	97 (44.9)
Poor	119 (55.1)
IVH, n (%)	118 (54.6)
Number of EVDs placed per patient, mean (SD)	1.52 (0.76)
EVD duration in days, median (IQR)	15 (10–22)
EVD sites, n (%)	
Kocher	184 (85.2)
Non-Kocher	32 (14.8)
GCS, Glasgow Coma Scale; IVH, intraventricular hemorrhage; IQR, interquartile range; SD, standard deviation; range; SD, standard deviation, † Good if GCS > 13; poor if GCS ≤ 12† Good if GCS > 13; poor if GCS ≤ 12	

Factors associated with VAI

VAIs occurred in 23/216 patients (10.6%). As presented in Table 2, age, sex, initial mental status, presence of IVH, underlying diagnosis, fever over 38.0°C, and number of CSF collections were not statistically different between VAI and non-VAI groups. On the other hand, a longer operation time was observed in the VAI group than in the non-VAI group (72 minutes vs. 40 minutes, $P < 0.001$), and the duration of the first EVD catheter was significantly shorter in the VAI group (9.7 days vs. 11.8 days, $P = 0.018$), whereas the total duration of EVD catheterizations was significantly longer in the VAI group (28.0 days vs. 16.1 days, $P < 0.001$). The proportion of patients who received EVD placements via non-Kocher's point at least once was significantly higher in the VAI group (34.7% vs. 12.5%, $P = 0.010$). The proportions of patients with concomitant craniotomy surgeries during EVD placement, CSF leakage, and other systemic infection were significantly higher in the VAI group.

Table 2
Univariate analysis of factors associated with VAI

Variables	VAI (n = 23)	No VAI (n = 193)	P-value
Age, mean (SD)	56.4 (16.6)	59.2 (14.8)	0.405
Sex, n (%)			0.423
Male	8 (34.8)	84 (43.5)	
Female	15 (65.2)	109 (56.5)	
Operation time in minutes, median (IQR)	72 (50–264)	40 (30–65)	< 0.001
Comorbidities, n (%)			
Hypertension	10 (43.5)	107 (55.4)	0.376
Diabetes Mellitus	3 (13.0)	33 (17.1)	0.773
Diagnosis, n (%)			0.382
Hemorrhage	16 (69.6)	145 (75.1)	
Ischemia	0 (0)	12 (6.2)	
Tumor	5 (21.7)	23 (11.9)	
Trauma	2 (8.7)	9 (4.7)	
Others	0 (0)	4 (2.1)	
Initial mental status†, n (%)			0.510
Good	12 (52.2)	85 (44.0)	
Poor	11 (47.8)	108 (56.0)	
IVH, n (%)	12 (52.2)	106 (54.9)	0.782
First EVD duration, mean (SD)	9.7 (4.2)	11.8 (4.0)	0.018
Total EVD duration, mean (SD)	28.0 (14.2)	16.1 (8.7)	< 0.001
EVD sites, n (%)			0.010
CSF, cerebrospinal fluid; EVD, external ventricular drainage; GCS, Glasgow Coma Scale; IQR, interquartile range; mRS, modified Rankin scale; VAI, ventriculostomy-associated infection; VPS, ventriculo-peritoneal shunt			
† Good if GCS > 13; poor if GCS ≤ 12			
‡ Favorable if mRS ≤ 2; unfavorable if mRS > 3			

Variables	VAI (n = 23)	No VAI (n = 193)	P-value
Kocher	15 (65.2)	169 (87.5)	
Non-Kocher	8 (34.7)	24 (12.5)	
Concomitant craniotomy, n (%)	20 (87.0)	119 (61.7)	0.019
CSF leak, n (%)	2 (8.7)	3 (1.6)	0.032
CSF collections, mean (SD)	3.0 (2.3)	3.5 (2.7)	0.377
Other infection, n (%)	7 (30.4)	18 (9.3)	0.012
Fever > 38°C, n (%)	21 (91.3)	150 (77.7)	0.124
90-day mRS‡			> 0.999
Favorable	8 (34.8)	64 (33.2)	
Unfavorable	15 (65.2)	129 (66.8)	
90-day VPS placement, n (%)	13 (56.5)	94 (50.3)	0.468
CSF, cerebrospinal fluid; EVD, external ventricular drainage; GCS, Glasgow Coma Scale; IQR, interquartile range; mRS, modified Rankin scale; VAI, ventriculostomy-associated infection; VPS, ventriculo-peritoneal shunt			
† Good if GCS > 13; poor if GCS ≤ 12			
‡ Favorable if mRS ≤ 2; unfavorable if mRS > 3			

Binary logistic regression was performed with variables with *P*-value < 0.10 and revealed that shorter duration of the first EVD catheter, longer total duration of EVD catheterizations, EVD placement at a non-Kocher's point, and presence of other systemic infection were independently associated with VAI (Table 3).

Table 3
Logistic regression analysis of VAI

Variables	OR (95% CI)	P-value
1st EVD duration	0.095 (0.025–0.354)	< 0.001
Total EVD duration	1.128 (1.069–1.189)	< 0.001
Non-Kocher's point	4.545 (1.397–14.706)	0.012
Other infection	5.117 (1.245–21.042)	0.024
CI, confidence interval; EVD, external ventricular drainage; OR, odds ratio; VAI, ventriculostomy-associated infection		

Timing of infection

VAI occurred after a median of nine days (IQR 4–16) since initial EVD placement. Patients who were not diagnosed with VAI within the first 10 days revealed a comparatively low rate of developing VAI ($n = 8/147$, 5.4%). Among 23 patients with VAI, 18 (78.3%) experienced VAI when their first EVD catheter was in place.

VAI in patients without and with prophylactic EVD exchanges

Among the 216 patients, 73 (33.8%) received prophylactic EVD catheter exchanges at a mean of 12.4 days. The duration of first EVD catheters and the total duration of EVD catheterizations were shorter in patients without prophylactic catheter exchanges. Patients with prophylactic catheter exchanges were more likely to have fever over 38.0°C (74.8% vs. 87.7%, $P = 0.033$) and VPS placement within 90 days (44.1% vs. 60.3%, $P = 0.031$), but there was no statistical difference in VAI rates between the two groups, with 12.6% vs. 6.8% ($P = 0.247$) for patients without prophylactic catheter exchanges and patients with prophylactic catheter exchanges, respectively (Table 4). For patients without prophylactic catheter exchanges, VAI rate was lower in those who maintained EVD ≥ 14 days than those who maintained EVD < 14 days, but the difference was not statistically significant (7.0% vs. 15.0%, $P = 0.272$).

Table 4

Univariate analysis of factors associated with VAI in patient without and with prophylactic EVD exchanges

Variables	No prophylactic EVD exchange (n = 143)	Prophylactic EVD exchange (n = 73)	P-value
Age, mean (SD)	58.8 (15.2)	59.1 (14.8)	0.878
Sex n (%)			0.663
Male	59 (41.3)	33 (45.2)	
Female	84 (58.7)	40 (54.8)	
Operation time in minutes, median (IQR)	41 (30–67)	45 (31–115)	0.276
Comorbidities, n (%)			
Hypertension	81 (56.6)	36 (49.3)	0.316
Diabetes Mellitus	23 (16.1)	13 (17.8)	0.847
Diagnosis, n (%)			0.666
Hemorrhage	103 (72.0)	58 (79.5)	
Ischemia	9 (6.3)	3 (4.1)	
Tumor	19 (13.3)	9 (12.3)	
Trauma	8 (5.6)	3 (4.1)	
Others	4 (2.8)	0 (0.0)	
Initial mental status†, n (%)			0.665
Good	66 (46.2)	31 (42.5)	
Poor	77 (53.8)	42 (57.5)	
IVH, n (%)	74 (51.7)	44 (61.1)	0.245

CSF, cerebrospinal fluid; EVD, external ventricular drainage; GCS, Glasgow Coma Scale; IQR,

interquartile range; mRS, modified Rankin scale; VAI, ventriculostomy-associated infection;

VPS, ventriculo-peritoneal shunt

† Good if GCS > 13; poor if GCS ≤ 12

‡ Favorable if mRS ≤ 2; unfavorable if mRS > 3

Variables	No prophylactic EVD exchange (n = 143)	Prophylactic EVD exchange (n = 73)	P-value
First EVD duration, mean (SD)	11.2 (4.1)	12.4 (3.9)	0.044
Total EVD duration, mean (SD)	13.6 (9.0)	25.3 (8.9)	< 0.001
EVD site, n(%)			0.420
Kocher	124 (86.7)	60 (82.2)	
Non-Kocher	19 (13.3)	13 (17.8)	
VAI, n (%)	18 (12.6)	5 (6.8)	0.247
Concomitant craniotomy, n (%)	90 (62.9)	49 (67.1)	0.553
CSF leak, n (%)	3 (2.1)	2 (2.7)	> 0.999
Other infection, n (%)	17 (11.9)	8 (11.0)	> 0.999
Fever > 38°C, n (%)	107 (74.8)	64 (87.7)	0.033
90-day mRS‡, n (%)			> 0.999
Good	48 (33.6)	24 (32.9)	
Poor	95 (66.4)	49 (67.1)	
90-day VPS placement, n (%)	63 (44.1)	44 (60.3)	0.031
CSF, cerebrospinal fluid; EVD, external ventricular drainage; GCS, Glasgow Coma Scale; IQR, interquartile range; mRS, modified Rankin scale; VAI, ventriculostomy-associated infection; VPS, ventriculo-peritoneal shunt			
† Good if GCS > 13; poor if GCS ≤ 12			
‡ Favorable if mRS ≤ 2; unfavorable if mRS > 3			

Microbiology

The most commonly identified pathogens were coagulase-negative Staphylococcus (CoNS) including Staphylococcus epidermidis, Staphylococcus hominis, and Staphylococcus lugdunensis. These CoNS, Enterococcus species, and Acinetobacter species constituted approximately 80% of all identified microorganisms. The microbiology result is summarized in Table 5

Table 5
Microbiology of VAI

Identified organisms	n = 23	%
CoNS	9	39.1
Acinetobacter species	5	21.7
Enterococcus species	4	17.4
Staphylococcus aureus	2	8.7
Pseudomonas species	1	4.3
Klebsiella species	1	4.3
Nocardia species	1	4.3
CoNS, Coagulase-negative Staphylococcus; VAI, ventriculostomy-associated infection		

Discussion

Analysis of 216 patients with 328 EVD catheterizations for 3370 catheter days revealed 23 VAIs, resulting in a VAI incidence of 10.6%. Important factors associated with VAI were shorter duration of first EVD catheterization, longer total duration of EVD catheterization, concomitant craniotomy surgery, catheterization in non-Kocher's point, CSF leak, and other systemic infection. Among these factors, shorter duration of first EVD catheterization, longer total duration of EVD catheterization, catheterization in non-Kocher's point, and other systemic infection were independently associated with VAI. VAI rates in patients who did and did not receive prophylactic EVD exchanges were not statistically different (6.8% vs. 12.6%, $P = 0.247$). The most commonly identified microorganism was CoNS, followed by gram-negative organisms such as *Acinetobacter* species and *Enterococcus* species.

VAI is a serious complication of the EVD procedure, resulting in prolonged hospital stay, unfavorable outcomes, and in-hospital mortality [10]. In general, three routes of CSF infection are suggested: 1) inoculation of skin flora during surgery, 2) manipulation during the CSF collection procedure, and 3) retrograde migration via the EVD tract [7]. In the current study, the numbers of CSF collections before VAI was identified between the VAI group and the non-VAI group were not statistically different (3.0 vs. 3.5, $P = 0.337$), consistent with a recent study by Sweid et al. who demonstrated that routine CSF collection and CSF collection when needed were not associated with VAI. [11] Our study suggests that CSF collection itself may not be a significant risk factor for VAI, provided that the closed CSF drainage system is not breached.

To reduce the risk of retrograde colonization, Mayhall et al. suggested prophylactic EVD exchanges in five-day intervals [12]. However, various investigators questioned this recommendation. Holloway et al. reported in their analysis of 584 patients with ventriculostomy that EVD catheters replaced prior to five

days did not lower infection rates compared to catheters replaced at longer intervals [13]. Later, a randomized controlled trial demonstrated that regular EVD changes at five-day intervals failed to reduce VAI [14]. More recently, a study by Katzier et al. revealed that a group of patients who received elective EVD changes every five days had a higher VAI rate than a group of patients who received EVD changes only when clinically necessary (32% vs. 8%). The authors suggested that a prophylactic EVD catheter change increased the incidence of VAI, and that inoculation of skin flora during the procedure was the primary contributing factor for VAI risk [7]. The researchers' analysis revealed that the prophylactic catheter exchanges in a 14-day interval did not lower VAI rates (6.8% vs. 12.6%, $P = 0.247$). The higher rate of VAI in patients without prophylactic EVD exchanges is because most VAIs occurred earlier than prophylactic catheter exchanges were considered, so that the patients with early VAIs belonged to the group of patients without prophylactic EVD exchange. Perhaps a more effective approach to control the risks of retrograde colonization or biofilm formation on the catheter surface than planning a catheter exchange at a certain interval is to implement EVD bundle approaches that consist of various infection prevention measures and use of silver-coated or antibiotic-impregnated EVD catheters [15–18]. Such actions have begun to be applied in the study institutions and were not reflected in this study.

In this study, the total duration of EVD catheterization was longer in patients with VAI than those without VAI (28.0 days vs. 16.1 days, $P < 0.001$). Whether the duration of EVD placement contributes to VAI is controversial. Several studies argued that prolonged EVD placement duration is a major risk factor for VAI [12, 13, 19–21]. However, there are a few studies suggesting that duration of EVD placement is not associated with an increased risk for VAI. Lo et al. investigated 199 patients with 269 EVDs and recognized that the duration of drainage was not an independent risk factor for infection [8]. A similar finding was presented by Hagel et al., who demonstrated no significant difference in the duration between first EVD placement and the occurrence of VAI and EVD removal in patients without VAI [22]. The authors noted that interpretation of previous studies that dealt with VAI was complicated because some studies used cumulative infection risks while other studies used daily infection risks. In the present study, the duration of first EVD catheter was shorter in patients with VAI than those without (9.70 days vs. 11.81 days, $P = 0.018$), likely because infected catheters were replaced as soon as possible. Once VAI was noticed, a general practice was to maintain CSF drainage until three consecutive negative CSF culture results, performed in a two-to-three-day interval, were confirmed. Therefore, a prolonged EVD placement in this study was more likely to be the result of VAI, and not vice versa. Due to the multifactorial nature of VAI and the complexity of analysis of contributing factors, the influence of catheterization duration on VAI is not clearly elucidated. However, as prolonged EVD catheter placement can interfere with early ambulation and discharge of patients, continuous efforts should be made to evaluate the necessity of maintaining EVD catheters in each patient and to remove the catheters as soon as possible.

On multivariate analysis, EVD catheterization via non-Kocher's point was an independent predictor of VAI. 32 patients received EVD catheter placements at non-Kocher's point, including Paine's point, Frazier's point, and at the cisterna magna to the third ventricle. Among them, 27 had EVD placements during craniotomy operations with long operation hours, exposing the surgical sites to a higher risk of microorganism inoculation. In addition, the authors suspect that EVD catheters inserted at entry points on

the dependent position would be more difficult to maintain in an aseptic fashion, and this might contribute to the increased risk of VAI. Whether VAI risks differ by EVD entry point can be a topic of future studies.

CoNS species were the most commonly identified microorganisms (39.1%) in this study, consistent with several previous studies [6, 8, 22, 23]. A notable finding is that *Acinetobacter* species (21.7%) and *Enterococci* species (17.4%) also were frequently identified. As in peripheral line- and central line-associated bloodstream infections [24, 25], the incidence and significance of gram-negative rods (GNR) in CSF infection have increased over the past few decades [7, 8, 21, 26, 27]. The increased proportions of *Acinetobacter* and *Enterococcus* could be in part related to the shift of microorganism populations in intensive care units toward gram-negative organisms [28, 29]. The emergence and prevalence of multi-drug resistant GNR are becoming a significant threat to the healthcare system. As prolonged use of prophylactic antibiotics targeting gram-positive organisms is considered one of the reasons for such a microbiologic shift [7], the benefits and risks of prolonged use of prophylactic antibiotics in patients with EVD catheters should be reconsidered and reflected in clinical practice.

This study has several limitations. Its retrospective study design involved intrinsic limitations such as selection bias and incomplete data. As the protocols for placement and management of EVD catheters are heterogeneous and can differ by institution, the generalizability of our findings might be limited. In addition, to diagnose VAI, patients' infectious signs and symptoms were not considered so it is impossible to completely exclude contaminations or colonization from true infections and to include culture negative VAIs, especially if prophylactic antibiotics were used in all cases. However, considering that it is often difficult or impossible to recognize signs and symptoms in patients with EVD catheters due to their deteriorated neurological status, the authors believe that their definition of VAI was practical. Lastly, use of antibiotic-impregnated EVD catheters and implementation of the EVD care bundle, which have become popular aspects of EVD procedures for the control of VAI, would have allowed for more effective management of the risk of VAI and improved clinical outcomes.

Conclusion

This study demonstrated VAI in 23/216 patients (10.6%) and 23/328 catheters (7.0%). VAI was independently associated with a shorter duration of first EVD catheter, a longer duration of total EVD, catheterization at a non-Kocher's point, and other systemic infections. Prophylactic EVD exchange at 14 days did not lower the risk of VAI.

Abbreviations

CI = confidence interval, CoNS = coagulase-negative *Staphylococcus*, CSF = cerebrospinal fluid, EVD = external ventricular drainage, GCS = Glasgow Coma Scale, GNR = gram-negative rod, IQR = interquartile range, IVH = intraventricular hemorrhage; mRS = modified Rankin Scale, SD = standard deviation; VAI = ventriculostomy-associated infection, VPS = ventriculo-peritoneal shunt

Declarations

Ethics approval: The Yonsei University Institutional Review Board waived the need for obtaining informed patient consent for this retrospective study. All methods were carried out in accordance with relevant guidelines and regulation.

Consent to participate: Informed consent was waived by the IRB due to the determination of minimal risk of the study.

Consent for publication: All authors agreed for publication of the manuscript.

Originality: This manuscript is original and has not been submitted for publications nor has it been published elsewhere.

Conflict of interest statements

The authors declare that they have no conflict of interest.

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Authors' contribution: JK, JHK, and SKP designed the study. JK, WL, HJH, KYP, JC, YBK, JYJ, and SKP managed the patient recruitment and data acquisition. JK and SKP analyzed data. JK wrote the first draft of the manuscript and performed statistical analysis. SKP supervised the manuscript and provided the critical revision. All authors contributed to and approved the final manuscript.

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Checklist for retrospective study: STROBE

Availability of data and material

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

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