DOI: 10.4274/gulhane.galenos.2026.48243
Gulhane Med J 2026;68(2):138-146

Influence of age and cerebrospinal fluid diversion techniques on infection risk in pediatric hydrocephalus: a 10-year single-center experience

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Cite this article as: Kayhan S, Doğan A, Kırmızıgöz Ş, Ezgu MC, Durmaz MO, Evleksiz Karımzada D, et al. Influence of age and cerebrospinal fluid diversion techniques on infection risk in pediatric hydrocephalus: a 10-year single-center experience. *Gulhane Med J.* 2026;68(2):138-146.

Date submitted:
04.11.2025
Date accepted:
06.04.2026
Epub:
11.06.2026
Publication Date:
16.06.2026

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Keywords: Hydrocephalus, infection, shunt, endoscopic third ventriculostomy, Ommaya reservoir

ABSTRACT

Aims: Hydrocephalus in children can be treated using various surgical techniques, each associated with distinct risks of infection and revision. This study aimed to evaluate and compare these risks associated with different surgical approaches in pediatric patients.

Methods: This retrospective study included pediatric patients aged 0-60 months who underwent surgical treatment of hydrocephalus between January 2010 and October 2020 at a tertiary neurosurgical centre. Demographic, clinical, and laboratory data were analysed, including cerebrospinal fluid (CSF) protein levels and microbiological culture results. The primary endpoint was the occurrence of postoperative infection, which was compared across surgical techniques and age groups.

Results: Eighty-seven children (mean age 11±3 months; 56.3% male) were included. Five surgical techniques were performed: ventriculoperitoneal shunting (VPS), external ventricular drainage, Ommaya reservoir insertion, endoscopic third ventriculostomy (ETV), and combined ETV+VPS. Infection occurred in 12 patients (13.8%), with significantly higher rates in neonates than in older children (25.9% vs. 8.3%, p=0.042). Among procedures, infections were more frequent in patients who underwent Ommaya reservoir implantation than in patients treated with other methods (28% vs. 8%, p=0.034). CSF protein levels showed no significant correlation with age or sex.

Conclusions: Neonatal age and Ommaya reservoir use were associated with an increased risk of infection in pediatric hydrocephalus. Careful patient selection and early conversion to definitive shunt procedures may help reduce infection-related complications.

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Introduction

Hydrocephalus is a common condition in the pediatric population and is associated with significant morbidity and mortality. As the surgical diversion of cerebrospinal fluid (CSF) is the treatment option of choice in hydrocephalus, various surgical techniques can be applied for successful clinical outcomes (1,2). Shunting is the most frequent and effective treatment for pediatric hydrocephalus worldwide. Endoscopic techniques are also in use for the definitive treatment of hydrocephalus (3). Meanwhile, external ventricular drainage (EVD) systems are used especially in premature newborns and low birth-weight infants before the permanent treatment methods are applied (4). Temporary procedures for CSF diversion are percutaneous lumbar or ventricular CSF aspiration and external drainage using a ventriculosubgaleal shunt, EVD system with a catheter and a bag, or a ventricular catheter with a subcutaneous reservoir (Ommaya reservoir) (5). The Ommaya reservoir is one of the temporary drainage systems, especially for children with post-hemorrhagic hydrocephalus (6). Ventriculoperitoneal (VP) shunt insertion is the preferred method, but it frequently fails in premature infants and low birth-weight newborns (7).

Infection is the primary risk associated with temporary CSF diversion procedures. Prolonged drainage may cause serious CSF infections, such as meningitis or ventriculitis (8). To avoid this severe complication, antibacterial catheters are introduced for surgical procedures (9,10). The most straightforward approach to overcome this serious complication is to shorten the drainage period and perform definitive treatment for hydrocephalus.

Despite the widespread use of multiple CSF diversion techniques in pediatric hydrocephalus, comparative data regarding procedure-specific infection risks remain limited. Moreover, the impact of patient age, especially the neonatal period, on infection rates across different surgical strategies has not been sufficiently clarified. Accordingly, this study aimed to assess postoperative infection rates following different CSF diversion procedures in pediatric hydrocephalus and to identify age-related differences in infection risk.

Methods

Patients and study design

Data from 87 pediatric patients treated for hydrocephalus in our department between January 2010 and October 2020 were retrospectively reviewed (Figure 1). The study population comprised children aged 0-60 months with radiologically and clinically confirmed hydrocephalus who underwent surgical intervention during this period. The sample size was determined by the number of eligible patients treated during the study period; no a priori power analysis was performed.

Patient histories and physical examination findings were recorded, and their etiological, clinical, and laboratory

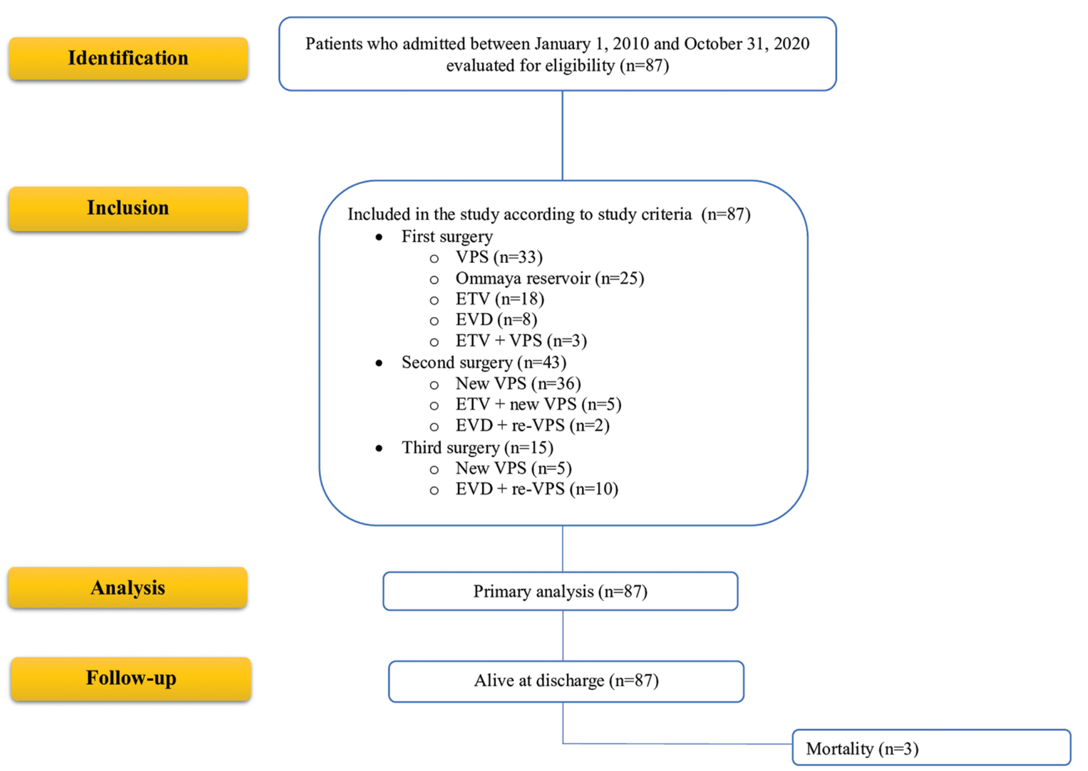

Figure 1. Flow diagram

ETV: Endoscopic third ventriculostomy, EVD: External ventricular drainage, VPS: Ventriculoperitoneal shunt characteristics were analysed. Eligible patients underwent one of the primary CSF diversion procedures: VP shunting (VPS), EVD, Ommaya reservoir insertion, endoscopic third ventriculostomy (ETV), or combined ETV+VPS. All patients had complete documentation at the time of surgery, including demographic data, operative notes, and postoperative follow-up sufficient to evaluate outcomes. Intraoperative CSF protein measurements and postoperative microbiological assessments were available for infection-related analyses.

The indication for surgery was established based on the development of clinical symptoms and signs of increased intracranial pressure. Cranial computed tomography (CT) was performed preoperatively and postoperatively in all patients to confirm ventricular dilatation and assess the effectiveness of the surgical intervention. Surgical risks were explained to the parents, and informed consent was obtained before each procedure.

The indication for surgery and the type of surgery were always determined based on the patient's clinical and radiological characteristics, in close cooperation with the neonatologist. CSF samples were obtained intraoperatively in all patients for microbiological culture and biochemical analysis. The rate of infection was compared statistically across patient gender and age groups. In addition, CSF protein levels were compared for each group and each surgical technique.

Management of postoperative shunt infection

Postoperative infection was diagnosed in patients who developed clinical signs suggestive of infection during follow-up, including fever, neurological deterioration, or shunt dysfunction, and whose diagnoses were supported by laboratory findings such as elevated inflammatory markers. CSF for microbiological analysis was obtained only in cases with clinical suspicion of infection. Infection was confirmed by a positive CSF culture; only culture-proven cases were classified as infections for statistical analysis. Accordingly, in patients diagnosed with postoperative shunt infection, the infected shunt system was completely removed, and an EVD was placed to maintain CSF diversion. This decision was based on clinical improvement (reduction of fever, disappearance of restlessness and signs of systemic infection), normalization of CSF findings (cell count, glucose, and protein), and two consecutive sterile CSF cultures taken at least 48 hours apart after completion of a full course of intravenous antibiotic treatment. In all cases, the new shunt was placed through a different entry site.

Ethical Approval

The Non-Interventional Scientific Research Ethics Committee of the University of Health Sciences, Türkiye, Gülhane Training and Research Hospital approved the study (approval no: 2020-419, date: 17.12.2020). This study was conducted in accordance with the STROBE guidelines and the Helsinki Declaration (11).

Study groups

Five surgical protocols were applied to the patients: VPS, ETV, simultaneous VPS+ETV, EVD, and Ommaya reservoir insertion. Endoscopic irrigation was also performed during ETV and ETV+VPS surgeries (Figure 1).

Surgical techniques

All procedures were performed under general anesthesia in the supine position, using a standardized sterile technique. The choice of surgical approach was based on patient age, etiology of hydrocephalus, clinical condition, and radiological findings. The ventricular catheter was inserted into the lateral ventricle through a frontal burr hole, preferentially targeting the most dilated ventricle.

VPS implantation was performed using a frontal burr hole, and the ventricular catheter was placed into the lateral ventricle. A valve-regulated shunt system was used, and the distal catheter was tunneled subcutaneously and inserted into the peritoneal cavity. We used position-sensitive Christoph Miethke® paediGAV valves (Aesculap, Tuttlingen, Germany) with opening pressures of 4 or 9 cm H_2O in a horizontal position and 24 cm H_2O in a vertical position. ETV was performed via a frontal approach using a rigid neuroendoscope (Karl Storz GmbH & Co. KG, Tuttlingen, Germany). After entering the lateral ventricle, the endoscope was advanced into the third ventricle. The floor of the third ventricle was identified, and fenestration was performed at the tuber cinereum. Intraventricular irrigation was carried out using warmed Ringer's lactate solution.

EVD was established by inserting a ventricular catheter into the lateral ventricle through a frontal burr hole. The catheter was connected to a closed external drainage system (DESU, Ankara, Türkiye), allowing continuous CSF drainage. Ommaya reservoir implantation was performed; a ventricular catheter connected to a subcutaneous reservoir was inserted into the lateral ventricle through a frontal burr hole. The reservoir was positioned in a subgaleal pocket. CSF drainage was performed intermittently via reservoir puncture. We used either right-angled or straight CSF reservoir systems (Medtronic Inc., Goleta, CA, USA).

In selected cases, ETV and VPS were performed during the same surgical session to provide combined CSF diversion. CSF samples were obtained intraoperatively for biochemical analysis and culture when clinically indicated.

All patients underwent cranial CT to confirm catheter position and the presence of ventricular decompression.

Statistical Analysis

Numerical variables of patient data were expressed as mean ± standard error of the mean and minimum (lowest) - maximum (highest values). Categorical variables were presented as the number of patients (n) and the percentage (%) using descriptive statistics. The distributional properties of numerical variables were evaluated using the Shapiro-Wilk test. The homogeneity of the variances was analysed by Levene's test. The Student's t-test was used to compare two independent groups when the data showed a normal distribution and parametric test assumptions were satisfied; one-way ANOVA followed by Fisher's least significant difference post-hoc test was used to compare more than two independent groups. If parametric test assumptions were not met, the Mann-Whitney U test was used for comparisons between two independent groups, and the Kruskal-Wallis H test was used for comparisons among more than two independent groups. The relationship between categorical data in independent groups was evaluated with the chi-square (χ^2) test. If the assumptions of the chi-square test were not met, Fisher's exact test or the Fisher-Freeman-Halton exact test was used, depending on group characteristics.

Due to the relatively small number of patients within individual surgical subgroups, an additional dichotomised analysis was performed, comparing patients who underwent Ommaya reservoir implantation with those who underwent all other procedures combined. This approach was adopted to improve statistical interpretability and to explore potential differences in infection risk that might not be detectable in multi-group comparisons with limited sample sizes. Differences at the $p<0.05$ level were considered statistically significant. Data were analyzed using IBM SPSS version 25.0 (Armonk, NY, USA).

Results

Baseline demographic and clinical data

A total of 87 children underwent surgical treatment for hydrocephalus over 10 years; 49 (56.3%) were male. The mean age at first surgery was 11.0 months (range, 0-60 months), with a mean body weight of 7,250 g and a mean follow-up of 25.2 months (Table 1). Post-hemorrhagic hydrocephalus was the most common etiology (n=32, 36.8%), followed by spina bifida, aqueductal stenosis, tumors, post-traumatic hydrocephalus, and other causes. During follow-up, three patients (3.4%) died.

Results of the first surgical interventions

VPS insertion was the most common first procedure (n=33), followed by Ommaya reservoir (n=25), ETV (n=18), EVD (n=8), and VPS+ETV (n=3). Mean CSF glucose was 46.2±3.0 mg/dL, with no findings suggestive of acute bacterial infection. CSF protein levels were ≤60 mg/dL in 17 patients (19.5%) and >60 mg/dL in 70 (80.5%); all intraoperative CSF cultures were negative (Table 2). VPS removal due to infection was required in two patients, in whom *Staphylococcus epidermidis* and *Staphylococcus aureus* were identified. VPS was reinserted after cultures were negative. The median duration of antibiotic therapy was 12 days, and the median hospital stay was 25 days.

Results of the second surgical intervention

A second surgical intervention was required in 43 patients (49.4%), primarily due to catheter obstruction. The mean interval between the first and second surgeries was 26.5 days. In five patients with ETV failure secondary to stoma closure, simultaneous VPS+ETV was performed. The majority of CSF cultures obtained during follow-up were negative (Table 2).

Following the second surgery, infections necessitating shunt removal and EVD placement occurred in 10 patients. Identified pathogens included *Staphylococcus epidermidis* (n=4), *Staphylococcus aureus* (n=2), *Klebsiella pneumoniae* (n=2), *Staphylococcus haemolyticus* (n=1), and *Enterococcus faecium* (n=1). The median duration of intravenous antibiotic therapy was 14 days, and the median hospital stay was 28 days.

Results of the third surgical intervention

Fifteen patients (17.2%) underwent a third surgical intervention, with a mean interval of 42.33 days following the second procedure. VPS reinsertion for shunt dysfunction was performed in 5 patients. All CSF cultures were negative, and no postoperative infections were observed after the third surgery.

Table 1. Demographic data and subgorups of the patients (n=87)

Variable	Mean ± SD	Range[a]
Age (month)	11.01±1.69	0.10-56
Birth weight (g)	7.250.00±513.32	1.950-17.900
Follow-up (month)	25.21±1.11	13-59
Age range (months)	**Groups**	**Number of patients n (%)**
Newborns	0-1	27 (31)
	2-60	60 (69)
	2-12	37 (42.5)
	13-60	23 (26.5)
	Total	87 (100)
Sex	Female	38 (43.7)
	Male	49 (56.3)
	Total	87 (100)
Etiology	Post-hemorrhagic	32 (36.8)
	Spina bifida	19 (21.8)
	Tumor	11 (12.6)
	Aquaductal stenosis	18 (20.7)
	Post-traumatic	5 (5.7)
	Others	2 (2.3)
	Total	87 (100)
Survey	Death	3 (3.4)
	Alive	84 (96.6)
	Total	87 (100)

SD: Standard deviation, [a]: Minimum-maximum value, n=Number

Table 2. The comprehensive data of all surgical procedures

Variable	
First surgical procedure	**Number of patients n (%)**
VPS	33 (37.9)
Ommaya reservoir	25 (28.7)
ETV	18 (20.7)
EVD	8 (9.2)
ETV+VPS	3 (3.4)
Infection based on the CSF protein level at the first surgery (mg/dL)	
CSF protein ≤60	17 (19.5)
CSF protein >60	70 (80.5)
CSF culture at the first surgery	
Negative	87 (100)
	Mean ± SD
CSF glucose level at the first surgery (mg/dL)	46.21±2.97
CSF protein level at the first surgery(mg/dL)	228.67±28.57
Time period between the first and second surgical procedure (days)	26.51±4.91
Cause of the second surgical procedure	**Number of patients n (%)**
Permanent CSF diversio n	33 (37.9)
Recurrence	5 (5.7)
Shunt dysfunction	3 (3.4)
Infection	2 (2.3)
Second surgical procedure	
VPS	36 (41.4)
ETV+VPS	5 (5.7)
Removal of VPS followed by EVD insertion and re-VPS, after antibiotherapy	2 (2.3)
Infection based on the CSF protein level at the second surgery (mg/dL)	
CSF protein ≤60	8 (9.2)
CSF protein >60	35 (40.2)
CSF culture at the second surgery[a]	
Negative	41 (47.1)
S. epidermidis	1 (1.1)
S. aureus	1 (1.1)
	Mean ± SD
CSF Glucose level at the second surgery (mg/dL)	42.84±2.63
CSF Protein level at the second surgery (mg/dL)	215.47±22.52
Time period between the second and third surgical procedure	42.33±5.01

Table 2. Continued

Variable	
	Mean ± SD
CSF Glucose level at the second surgery (mg/dL)	42.84±2.63
CSF Protein level at the second surgery (mg/dL)	215.47±22.52
Time period between the second and third surgical procedure	42.33±5.01
	Number of patients n (%)
Cause of the third surgical procedure	
Shunt dysfunction	5 (5.7)
Infection	10 (11.5)
Third surgical procedure	
New VPS	5 (5.7)
Removal of VPS, EVD insertion and re-VPS insertion after the antibiotherapy	10 (11.5)
Infection based on the CSF protein level at the third surgery (mg/dL)	
None (Not third surgical procedure)	72 (82.8)
CSF protein >60	15 (17.2)
CSF culture at the third surgery[a]	
Negative	5 (5.7)
S. epidermidis	4 (4.6)
S. aureus	2 (2.3)
Klebsiella pneumoniae	2 (2.3)
S. haemolyticus	1 (1.1)
Enterococcus faceum	1 (1.1)
	Mean ± SD
CSF Glucose level at the third surgery (mg/dL)	39.53±3.34
CSF Protein level at the third surgery (mg/dL)	275.40±37.76

[a]: CSF culture results obtained at the time of shunt removal in patients who developed infection after the relevant surgery, n=number
SD: Standard deviation, ETV: Endoscopic third ventriculostomy, EVD: External ventricular drainage, VPS: Ventriculoperitoneal shunt, CSF: Cerebrospinal fluid

Comparing infection rates according to gender and age

Infection occurred in 7 of 38 female patients (18.4%) and in 5 of 49 male patients (10.2%); there was no statistically significant difference between the groups (p=0.270). When the data were stratified by age, infection was observed in 7 of 27 neonates (25.9%) and in 5 of 60 patients aged 2-60 months (8.3%). The infection rate was significantly higher in neonates (p=0.042).

Comparing infection rates of surgical procedures

No statistically significant difference in infection rates was observed among surgical procedures. Although the Ommaya reservoir group demonstrated a higher infection rate (28%) compared with other procedures (6-12%), this difference did not reach statistical significance. However, following dichotomization, infection rates were significantly higher in the Ommaya group than in all other procedures combined (28% vs. 8%, p=0.034).

Comparison of CSF protein levels

CSF protein levels did not differ significantly by sex or between neonates (0-1 month) and older children (2-60 months) across the first three surgeries. However, when patients were stratified into detailed age groups, CSF protein levels were significantly higher in patients aged 2-12 months than in other age groups during the first and second surgeries ($p<0.05$), and no significant difference was observed at the third surgery.

Discussion

Hydrocephalus remains a significant health problem, particularly in premature and low birth-weight infants, and is associated with considerable morbidity and mortality in the pediatric population (4,6,12). Its prevalence is approximately 6 per 10,000 live births, yet it continues to represent an under-recognized condition despite its substantial clinical and economic burden (13,14).

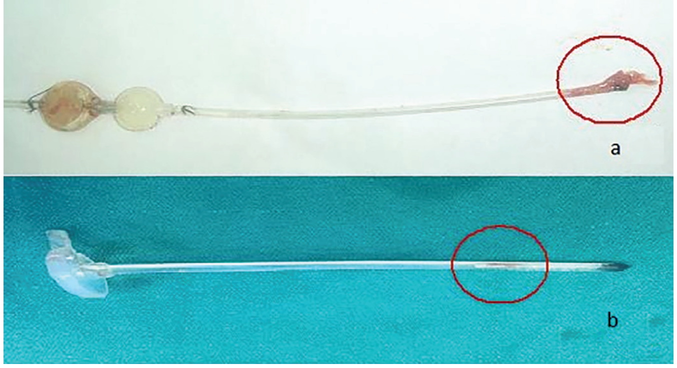

Figure 2. (a) Ventricular catheter tip of VP shunt occluded as a result of infection. (b) Ventricular tip of Ommaya reservoir occluded with particles

VP: Ventriculoperitoneal

A wide spectrum of etiologies contributes to pediatric hydrocephalus. In line with previous reports, post-hemorrhagic hydrocephalus was the most common cause in our series (36.8%), followed by spina bifida (21.8%) (15). Nearly half of the patients (49.4%) required a second surgical intervention, and 17.2% underwent a third procedure, supporting the notion that repeated surgeries are a frequent and often unavoidable aspect of disease management, particularly in post-hemorrhagic cases.

Gender differences are an important factor in the development of hydrocephalus. Enger et al. (16) showed that hydrocephalus is more frequent in male patients among 407 pediatric patients with hydrocephalus, which is consistent with our findings. There is no precise information on the cause of the male predominance in pediatric hydrocephalus.

Accurate and effective treatment is the first aim of pediatric neurosurgeons for hydrocephalus. Etiological factors affecting the development of hydrocephalus are elucidated day-by-day (17). Although neuroendoscopic techniques have increasingly been adopted in neurosurgical practice for the treatment of hydrocephalus, VPS is still most widely used and effective treatment modality (9,18). ETV is an established option for obstructive hydrocephalus, particularly in aqueductal stenosis. It has gradually spread, especially over the last three decades. In the literature, several studies have reported that simultaneous application of ETV and VPS in the same session is a reasonable approach (19,20). The rapid closure of the ventriculostomy is a frequently reported complication, especially in infants under one year of age and in cases of post-hemorrhagic hydrocephalus; it is attributed to immaturity of CSF circulation pathways, intraventricular inflammation, and clot formation, and it plays an important role in the selection of this combined procedure (21,22). Implementation of ETV in combination with VPS provides a potential dual route for CSF diversion, whereby in the event of early VPS failure, a functional ETV may help prevent acute intracranial hypertension and reduce the need for urgent shunt revision. Additionally, endoscopic lavage performed during ETV may facilitate clearance of intraventricular debris

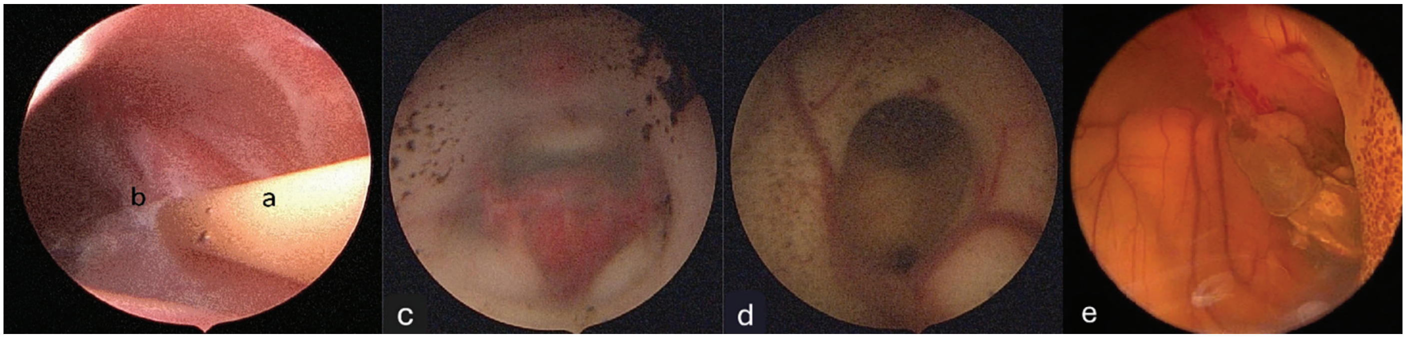

Figure 3. Dysfunctional VPS catheter (a) adhered to lateral ventricle wall (b). (c) Post-hemorrhagic particles around the tuber cinereum at the base of the third ventricle. (d) Particles on lateral ventricle walls and near the foramen of Monro, cleared by endoscopic irrigation. (e) Coagulum around the choroid plexus

VPS: Ventriculoperitoneal shunt

and potentially reduce infection risk (22,23). Although not a conventional approach, this strategy was adopted to optimise safety and long-term outcomes, particularly in high-risk patients with post-hemorrhagic hydrocephalus.

Temporary CSF diversion techniques, including EVD and Ommaya reservoirs, are valuable in patients with prematurity, poor general condition, or infection risk precluding immediate permanent shunting (5). These procedures allow enough time for the newborns to gain weight and transition to permanent shunt systems for the treatment of hydrocephalus. However, these approaches are not without complications (24). In our series, ventriculosubgaleal shunting was not utilized due to concerns regarding infection risk and limited long-term efficacy.

Infections are among the primary complications associated with the use of drainage systems. The incidence of infection after the surgical management of pediatric hydrocephalus is about 11% (14), while most of the infections occur within the 3 months after surgery (25). In our study, the overall infection rate was 13.7%. Coagulase-negative staphylococci were the cause of infection in 6 (50%) patients and *Staphylococcus aureus* in 3 (25%) patients, consistent with the literature. Coagulase-negative staphylococci (*Staphylococcus epidermidis*) and *Staphylococcus aureus* were the most frequently identified pathogens, reflecting the role of skin flora in shunt-related infections (8,16,26). Notably, infection rates increased following successive surgical interventions, rising from 2.3% after the first procedure to 11.5% after the second, highlighting the cumulative risk associated with multiple revisions.

Patient age is a well-established determinant of infection risk. Previous studies have demonstrated a markedly higher infection rate in younger infants (16,27,28). Consistent with these findings, neonates in our cohort had a significantly higher infection rate compared with older children (25.9% vs. 8.3%, $p<0.05$). This increased susceptibility is likely related to immunological immaturity, impaired skin barrier function, delayed wound healing, and prolonged hospitalization (29). Although infection rates were numerically higher in female patients, no statistically significant sex-related difference was observed.

The relationship between CSF protein levels and infection risk remains controversial. Yakut et al. (29) reviewed 290 patients with shunt infection and suggested that elevated protein levels may be associated with reinfection. We did not observe a significant association with either age or sex. However, higher protein levels were noted in the 2-12-month age group during early surgical stages, which may reflect disease severity or inflammatory burden.

Neuroendoscopic lavage has been proposed by Gaderer et al. (30) as a strategy to reduce infection and revision rates by clearing inflammatory debris from the ventricular system. In our limited cohort, no infections were observed in patients undergoing combined ETV and VPS with endoscopic lavage; however, the small sample size precludes definitive conclusions.

Procedure-specific infection rates remain a subject of debate. Lu et al. (31) reported significantly lower postoperative infection rates in the ETV group compared to VPS. In our series, infection occurred in 2 of 18 patients (11.1%) who underwent ETV and in 2 of 33 patients (6.1%) who underwent VPS as the initial procedure; no clear difference was observed, likely due to the limited sample size. In contrast, Palpan Flores et al. (32) reported an infection rate of 10.9% following Ommaya reservoir implantation and a 76.1% conversion rate to permanent shunting. Similarly, in our cohort, infection occurred in 28% of patients with Ommaya reservoirs, and all patients ultimately required permanent CSF diversion, consistent with previous findings (33). Notably, infection rates were significantly higher in the Ommaya group compared with rates for other procedures (28% vs. 8%, $p=0.034$), likely related to repeated reservoir access and the introduction of skin flora, despite antiseptic precautions. Therefore, the Ommaya reservoir should be used only for a short period and be converted to a permanent shunt as early as possible.

Mortality remains an important outcome in pediatric hydrocephalus. While previous studies have reported rates as high as 16.5% (22), the mortality rate in our series was 3.4%, with no deaths attributable to infection. The relatively short follow-up duration in our study may account for this lower rate.

Study Limitations

This study has several limitations that should be acknowledged. First, its retrospective, single-centre design inherently limits causal inference. However, potential selection bias was minimised because the surgical technique was chosen collaboratively by the neonatology and neurosurgery teams according to each patient's clinical and radiological findings, rather than by individual surgeon preference. Second, the relatively small overall sample size, particularly that of some subgroups such as ETV and combined ETV+VPS, reduces statistical power and may obscure subtle associations. Third, potential confounding factors, including gestational age, nutritional status, and antibiotic prophylaxis protocols, were not uniformly recorded and therefore could not be fully controlled. Fourth, surgical techniques and postoperative management may have evolved during the ten-year study period, potentially introducing variability in outcomes. Finally, the lack of long-term neurodevelopmental follow-up limits the assessment of functional outcomes beyond infection and revision rates.

Conclusion

Neonates demonstrated a nearly threefold higher risk of infection compared with older children, likely due to immunological immaturity and an impaired skin barrier. Use of an Ommaya reservoir was also associated with a significantly increased infection rate, underscoring the vulnerability of patients requiring temporary CSF diversion.

These findings identify patient age and diversion strategy as key, modifiable determinants of infection risk in pediatric hydrocephalus. Early transition from temporary to permanent CSF diversion, together with meticulous aseptic technique, appears essential to minimize complications. Given the substantial impact of infection on morbidity, reoperation rates, and healthcare costs, targeted preventive strategies are critical.

Further large-scale, multicenter studies are needed to refine patient selection and optimize treatment protocols.

Ethics

Ethics Committee Approval: The Non-Interventional Scientific Research Ethics Committee of the University of Health Sciences, Türkiye, Gülhane Training and Research Hospital approved the study (approval no: 2020-419, date: 17.12.2020).

Informed Consent: Surgical risks were explained to the parents, and informed consent was obtained before each procedure.

Acknowledgments

This study is derived from the corresponding author's master's thesis, titled "Evaluation of Surgical Techniques and Outcomes in Pediatric Patients with Hydrocephalus", which was completed in 2021 at the University of Health Sciences, Gülhane Faculty of Medicine, Department of Neurosurgery.

Footnotes

Authorship Contributions

Surgical and Medical Practices: S.K., A.D., Ş.K., M.C.E., M.O.D., Concept: S.K., Y.İ., Design: S.K., M.C.E., Y.İ., Data Collection or Processing: S.K., D.E., E.Y., Analysis or Interpretation: S.K., D.E., C.A., S.Y.S., Literature Search: S.K., Writing: S.K., Y.İ.

Conflict of Interest: The authors declared no conflict of interest.

Financial Disclosure: The authors declared that this study received no financial support.

References

1. Evleksiz Karimzada D, Can Ezgu M, Karimzada G, Izci Y. Ventricular anatomical differences-a different perspective on endoscopic treatment of pediatric hydrocephalus: anomalies, variations, and deformations. *World Neurosurg.* 2024;191:e80-e91.
2. Tully HM, Dobyns WB. Infantile hydrocephalus: a review of epidemiology, classification and causes. *Eur J Med Genet.* 2014;57(8):359-368.
3. Kamikawa S, Inui A, Kobayashi N, Kuwamura K, Kasuga M, Yamadori T, et al. Endoscopic treatment of hydrocephalus in children: a controlled study using newly developed Yamadori-type ventriculoscopes. *Minim Invasive Neurosurg.* 2001;44(1):25-30.
4. Cornips E, Van Calenbergh F, Plets C, Devlieger H, Casaer P. Use of external drainage for posthemorrhagic hydrocephalus in very low birth weight premature infants. *Childs Nerv Syst.* 1997;13(7):369-374.
5. Nee LS, Harun R, Sellamuthu P, Idris Z. Comparison between ventriculosubgaleal shunt and extraventricular drainage to treat acute hydrocephalus in adults. *Asian J Neurosurg.* 2017;12(4):659-663.
6. Tröbs RB, Sander V. Posthemorrhagic hydrocephalus in extremely low birth weight infants: Ommaya reservoir vs. ventriculoperitoneal shunt. *Childs Nerv Syst.* 2015;31(8):1261-1266.
7. Kuo MF. Surgical management of intraventricular hemorrhage and posthemorrhagic hydrocephalus in premature infants. *Biomed J.* 2020;43(3):268-276.
8. Jiménez-Mejías ME, Márquez-Rivas FJ. CNS infections in patients with temporary CSF shunts: diagnostic, preventive and therapeutic approach. *Enferm Infecc Microbiol Clin (Engl Ed).* 2020;38(2):49-53.
9. Izci Y, Secer H, Akay C, Gonul E. Initial experience with silver-impregnated polyurethane ventricular catheter for shunting of cerebrospinal fluid in patients with infected hydrocephalus. *Neurol Res.* 2009;31(3):234-237.
10. Secer HI, Kural C, Kaplan M, Kilic A, Duz B, Gonul E, et al. Comparison of the efficacies of antibiotic-impregnated and silver-impregnated ventricular catheters on the prevention of infections. An in vitro laboratory study. *Pediatr Neurosurg.* 2008;44(6):444-447.
11. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP, et al. Strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. *BMJ.* 2007;335(7624):806-808.
12. Paulsen AH, Lundar T, Lindegaard KF. Pediatric hydrocephalus: 40-year outcomes in 128 hydrocephalic patients treated with shunts during childhood. Assessment of surgical outcome, work participation, and health-related quality of life. *J Neurosurg Pediatr.* 2015;16(6):633-641.
13. Kahle KT, Kulkarni AV, Limbrick DD Jr, Warf BC. Hydrocephalus in children. *Lancet.* 2016;387(10020):788-799.
14. Wright Z, Larrew TW, Eskandari R. Pediatric hydrocephalus: current state of diagnosis and treatment. *Pediatr Rev.* 2016;37(11):478-490.
15. Holwerda JC, van Lindert EJ, Buis DR, Hoving EW; Dutch Pediatric Neurosurgery Study Group. Surgical intervention for hydrocephalus in infancy; etiology, age and treatment data in a Dutch cohort. *Childs Nerv Syst.* 2020;36(3):577-582.
16. Enger PØ, Svendsen F, Wester K. CSF shunt infections in children: experiences from a population-based study. *Acta Neurochir (Wien).* 2003;145(4):243-248; discussion 248.
17. Beuriat PA, Puget S, Cinalli G, Blauwblomme T, Beccaria K, Zerah M, et al. Hydrocephalus treatment in children: long-term outcome in 975 consecutive patients. *J Neurosurg Pediatr.* 2017;20(1):10-18.

18. Drake JM, Kestle JR, Milner R, Cinalli G, Boop F, Piatt J, et al. Randomized trial of cerebrospinal fluid shunt valve design in pediatric hydrocephalus. *Neurosurgery*. 1998;43(2):294-303; discussion 303-305.

19. Geyik M, Geyik S, Dogan A. Comparison of different endoscopic techniques for the treatment of hydrocephalus in children. *Turk Neurosurg.* 2022;32(2):271-276.

20. Shim KW, Kim DS, Choi JU. Simultaneous endoscopic third ventriculostomy and ventriculoperitoneal shunt for infantile hydrocephalus. *Childs Nerv Syst.* 2008;24(4):443-451.

21. Deopujari CE, Karmarkar VS, Shaikh ST. Endoscopic third ventriculostomy: success and failure. *J Korean Neurosurg Soc*. 2017;60(3):306-314.

22. Karımzada G, Kaya MB, Karımzada DE, Ezgü MC, Karımzada G, Kaya MB, et al. Postnatal management and outcomes of hydrocephalus in patients with myelomeningocele: a retrospective study from a single institution. *Hamidiye Med J.* 2025;6(1):43-49.

23. Koch D, Wagner W. Endoscopic third ventriculostomy in infants of less than 1 year of age: which factors influence the outcome? *Childs Nerv Syst.* 2004;20(6):405-411.

24. Willis B, Javalkar V, Vannemreddy P, Caldito G, Matsuyama J, Guthikonda B, et al. Ventricular reservoirs and ventriculoperitoneal shunts for premature infants with posthemorrhagic hydrocephalus: an institutional experience. *J Neurosurg Pediatr.* 2009;3(2):94-100.

25. Dinçer A, Kohan S, Özek MM. Is all “communicating” hydrocephalus really communicating? prospective study on the value of 3D-constructive ınterference in steady state sequence at 3T. *AJNR Am J Neuroradiol*. 2009;30(10):1898-1906.

26. Lee JK, Seok JY, Lee JH, Choi EH, Phi JH, Kim SK, et al. Incidence and risk factors of ventriculoperitoneal shunt ınfections in children: a study of 333 consecutive shunts in 6 years. *J Korean Med Sci.* 2012;27(12):1563-1568.

27. Pople IK, Bayston R, Hayward RD. Infection of cerebrospinal fluid shunts in infants: a study of etiological factors. *J Neurosurg.* 1992;77(1):29-36.

28. Renier D, Lacombe J, Pierre-Kahn A, Sainte-Rose C, Hirsch JF. Factors causing acute shunt infection. Computer analysis of 1174 operations. *J Neurosurg.* 1984;61(6):1072-1078.

29. Yakut N, Soysal A, Kepenekli Kadayifci E, Dalgic N, Yılmaz Ciftdogan D, Karaaslan A, et al. Ventriculoperitoneal shunt infections and re-infections in children: a multicentre retrospective study. *Br J Neurosurg*. 2018;32(2):196-200.

30. Gaderer C, Schaumann A, Schulz M, Thomale UW. Neuroendoscopic lavage for the treatment of CSF infection with hydrocephalus in children. *Childs Nerv Syst.* 2018;34(10):1893-1903.

31. Lu L, Chen H, Weng S, Xu Y. Endoscopic third ventriculostomy versus ventriculoperitoneal shunt in patients with obstructive hydrocephalus: meta-analysis of randomized controlled trials. *World Neurosurg.* 2019;129:334-340.

32. Palpan Flores A, Saceda Gutiérrez J, Brin Reyes JR, Sierra Tamayo J, Carceller Benito F. Risk factors associated with conversion of an Ommaya reservoir to a permanent cerebrospinal fluid shunt in preterm posthemorrhagic hydrocephalus. *J Neurosurg Pediatr.* 2020;25(4):417-424.

33. Mazzola CA, Choudhri AF, Auguste KI, Limbrick DD, Rogido M, Mitchell L, et al. Pediatric hydrocephalus: systematic literature review and evidence-based guidelines. Part 2: management of posthemorrhagic hydrocephalus in premature infants. *J Neurosurg Pediatr.* 2014;14(Suppl 1):8-23.