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A comparative analysis of lumboperitoneal shunt outcomes in patients with post-hemorrhagic and post-traumatic hydrocephalus

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Hydrocephalus, whether arising from post-hemorrhagic or post-traumatic origins, poses significant challenges in clinical management. Lumboperitoneal shunting (LPS) emerges as a viable therapeutic intervention, yet comparative analyses between these etiologies remain scarce. This retrospective study aims to compare the efficacy and safety of LPS placement in patients with post-hemorrhagic (PHH) and post-traumatic hydrocephalus (PTH). This retrospective study investigates shunting outcomes in patients aged 18 years or older diagnosed with PHH or PTH who underwent LPS between 2014 and 2018. Primary outcomes included shunt reoperation rates, with secondary outcomes encompassing modified Rankin Scale (mRS) and National Institute of Health Stroke Scale (NIHSS) scores, Evans index, complications, and length of hospital stay. Favorable outcomes were defined as an mRS score of 2 or less. A total of 34 PHH and 48 PTH patients were included, with baseline characteristics being similar between groups. Shunt reoperation rates were comparable between PHH (23.5%) and PTH (27.1%) groups ($P = 0.716$). At 2 years, favorable outcomes were observed in 82.4% of PHH patients and 72.9% of PTH patients ($P = 0.318$). NIHSS scores at discharge ($P = 0.230$) and at 2 years ($P = 0.530$) showed no significant differences. However, PHH patients exhibited shorter hospital stays post-LPS implantation ($P = 0.025$). LPS placement demonstrates comparable outcomes in patients with PHH and PTH, with similar rates of shunt reoperation and complications, as well as equivalent neurological outcomes. However, Notably, PTH patients exhibited a higher risk of shunt malfunction compared to PHH patients, along with prolonged hospital stays post-LPS implantation.

Keywords Cerebrospinal fluid shunt, Lumboperitoneal shunt, Hydrocephalus, Traumatic brain injury, Hemorrhagic stroke

Lumboperitoneal shunt (LPS), a procedure diverting cerebrospinal fluid (CSF) from the spinal subarachnoid space to the peritoneal cavity, has emerged as a crucial alternative for managing hydrocephalus since its inception in the 1950s[1,2]. n ideal indication for LPS is idiopathic normal pressure hydrocephalus (INPH), with Japan adopting it as the primary treatment for INPH patients[3]. In Japan, LPS has become the first option in patients with INPH[4,5]. However, recent developments have expanded its application to hydrocephalus types traditionally deemed unsuitable for LPS, such as post-hemorrhagic hydrocephalus (PHH) and post-traumatic hydrocephalus (PTH)[6].

PHH typically occurs as a consequence of spontaneous intracerebral hemorrhage (ICH), notably intraventricular hemorrhage (IVH) and subarachnoid hemorrhage (SAH)[7–9]. The incidence of hydrocephalus in IVH patients ranges from 51 to 89%, and in SAH patients from 15 to 37%[9]. PTH commonly arises as a complication of traumatic brain injury (TBI), with reported incidence rates ranging from 0.7–28.9%[10]. Recent studies have explored the benefits and risks of LPS implantation for communicating types of PHH or PTH, indicating its potential efficacy alongside risk of shunt failure[11,12]. However, there is a paucity of comparative data regarding the effectiveness of LPS specifically in patients with secondary hydrocephalus resulting from

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trauma or hemorrhage. Understanding the nuances of these distinct pathologies and their responses to LPS is vital, given the varied pathophysiological mechanisms at play.

This study aims to bridge the existing knowledge gap by conducting a comprehensive comparative analysis of LPS outcomes in patients with post-hemorrhagic and post-traumatic hydrocephalus. By evaluating both clinical and functional outcomes, alongside the incidence of complications and reoperations, we aspire to provide critical insights that could shape future treatment strategies for this complex patient population.

Methods

Study design

According to our clinical database, all patients aged 18 years or older who were diagnosed as PHH or PTH and underwent LPS from January 2014 to December 2018 at the West China Hospital of Sichuan University, were included in the study. Patients with a history of prior shunt including VPS, endoscopic third ventriculostomy (ETV), or LPS, or loss to follow-up, were excluded. The diagnosis of PTH or PHH was based on the history of previous hemorrhagic stroke or head trauma that is related to the occurrence of hydrocephalus, clinical symptoms, and brain imaging. MRI scans (including head, spinal cord, and CSF imaging) were sometimes required for some patients to prove that the communication of the ventricles with lumbar subarachnoid space is evident. Besides, Tap Test, infusion test, or external lumbar drainage was sometimes required in order to differentiate hydrocephalus from other diseases and select suitable patients before shunt implantation. We collected the baseline information consisting of age, sex, duration of hydrocephalus, etiology, Glasgow Coma Scale (GCS), modified Rankin Scale (mRS), National Institute of Health stroke scale (NIHSS), Evans index, and follow-up time. The shunting systems with programmable pressure valves (PPV) and anti-siphon valves were obtained from Medtronic (Minnesota, USA). All participants signed consents to participate in this study. All methods were carried out in accordance with the STROCSS criteria.

Outcomes

All patients underwent preoperative evaluation and were assessed at discharge from the hospital, with regular follow-up thereafter. The last follow-up date was December 2020. The primary outcome was the overall rate of shunt reoperation at the last follow-up. The decision to perform reoperation was made collaboratively by attending neurosurgeons and patients in cases of shunt obstruction, breakage, tubing exposure, malfunction, or severe infection necessitating shunt revision. The main secondary outcomes included functional outcomes (as assessed by the mRS and NIHSS), Evans index, mortality, and length of stay at discharge from the hospital and 2 years post-surgery. Any complications related to shunt implantation during follow-up were meticulously investigated. A favorable outcome was defined as an mRS score of 2 or less.

Statistical analysis

All data were analyzed using the statistical software program SPSS version 19 (IBM, Armonk, New York). The normality of quantitative data was assessed using the Kolmogorov-Smirnov test. Quantitative data were presented as mean ± standard deviation (SD) for normally distributed variables, and as median (range) for non-normally distributed variables. Categorical variables were expressed as numbers (percentages). For normally distributed quantitative data, the t-test was employed to compare differences between the two groups, while the Wilcoxon rank sum test was utilized for non-normally distributed quantitative data. Reoperation-free rate curves were constructed using the Kaplan-Meier method, and differences between the two groups were assessed using the log-rank test. Kaplan-Meier curves represent the probability of surviving past a certain point in time without experiencing the event of interest. The curve plots survival probability on the y-axis against time on the x-axis. Multiple Kaplan-Meier curves can be plotted on the same graph to compare survival probabilities between different groups. Statistical tests, such as the log-rank test, can be used to determine if differences between curves are significant. A p-value less than 0.05 (two-sided) was considered statistically significant.

Results

Patients

From January 2014 to December 2018, a total of 45 patients with PHH and 59 patients with PTH who underwent LPS surgery were initially screened for eligibility. Among them, 7 patients (6 in the PHH group and 1 in the PTH group) under 18 years of age were excluded, as well as 12 patients (4 in the PHH group and 8 in the PTH group) with a history of prior shunt surgery. Additionally, 1 patient in the PHH group and 2 patients in the PTH group were lost to follow-up. Consequently, a total of 82 patients were included in the study, comprising 34 patients in the PHH group and 48 patients in the PTH group.

As shown in Table 1, the baseline characteristics of these 2 groups were analyzed. The baseline characteristics were similar in the 2 groups in total aspects, including age ($P=0.067$), sex ($P=0.097$), time from onset to shunts ($P=0.249$), decompressive craniectomy ($P=0.913$), GCS ($P=0.899$), NIHSS ($P=0.996$), mRS ($P=0.720$), Evans index ($P=0.109$), and follow-up time ($P=0.788$).

Outcomes

The results revealed that as of December 2020, shunt reoperation was reported in 8 out of 34 patients (23.5%) in the PHH group and in 13 out of 48 patients (27.1%) in the PTH group, with no statistically significant difference observed ($P=0.716$). Table 2 displays the primary reasons for shunt reoperation. In the PHH group, obstruction (11.8%) was the most prevalent cause of shunt reoperation, while 4 patients required reoperation due to shunt malfunction, infection, exposure, or migration. Conversely, malfunction (14.6%) was the leading cause of shunt reoperation in the PTH group, with 4 patients undergoing reoperation for obstruction and 2 for

	PHH	PTH	*P* value
No. of patients	34	48	
Age, y, mean ± SD	52.7 ± 15.4	46.2 ± 15.8	0.067
Sex, n (%)			0.097
Male	23 (67.6%)	8 (16.7%)	
Female	11 (32.4%)	40 (83.3%)	
Time from onset to shunts, m, median (range)	1.0 (0.1-9.0)	1.0 (0.2-7.0)	0.249
Decompressive craniectomy before shunts, n (%)			0.913
Yes	16 (47.1%)	22 (45.8%)	
No	18 (52.9%)	26 (54.2%)	
GCS, n (%)			0.899
3–8	7 (20.6%)	10 (20.8%)	
9–12	20 (58.8%)	30 (62.5%)	
13–14	7 (20.6%)	8 (16.7%)	
NIHSS, median (range)	14.5 (1–38)	14 (1–36)	0.996
mRS, median (range)	3 (1–5)	3 (1–5)	0.720
Evans index, mean ± SD	0.34 ± 0.05	0.35 ± 0.04	0.109
Follow-up time, m, median (range)[†]	45.5 (21.0–82.0)	47.0 (19.7–73.0)	0.788

Table 1. Baseline characteristics. [†]Follow-up time defined as the time from shunt surgery to the last follow-up.

	PHH	PTH	*P* value
No. of patients	34	48	
Length of stay, d, median (range)	8.5 (4-139)	13 (4–92)	0.025
Shunt reoperation, n (%)	8 (23.5%)	13 (27.1%)	0.716
Obstruction	4 (11.8%)	4 (8.3%)	0.606
Malfunction	1 (2.9%)	7 (14.6%)	0.080
Infection	1 (2.9%)	1 (2.1%)	0.804
Exposure	1 (2.9%)	0 (0%)	0.232
Disconnection	0 (0%)	1 (2.1%)	0.397
Migration	1 (2.9%)	0 (0%)	0.232
Time to shunt reoperation, m, median (range)	1.8 (0.1–5.1)	2.45 (0.5-9.0)	0.347

Table 2. Shunting outcomes at the last follow-up.

infection or disconnection. The incidence of shunt malfunction was higher in the PTH group (14.6%) compared to the PHH group (2.9%), though not statistically significant ($P=0.080$). Moreover, the incidence of events necessitating reoperation, including obstruction, infection, exposure, disconnection, and migration, did not differ significantly between the two groups ($P>0.05$). Among the shunt reoperation patients, in the PHH group, 3 patients underwent LPS placement, and 5 patients underwent VPS placement; in the PTH group, 4 patients underwent LPS placement, 8 patients underwent VPS placement, and 1 patient underwent both LPS and VPS placement.

The reoperation-free rate curve, depicted in Fig. 1 using the Kaplan-Meier method, revealed no statistically significant difference between the two groups ($P=0.686$).

Regarding secondary outcomes, including functional outcomes (as assessed by mRS and NIHSS scores), Evans index, mortality, and length of hospital stay, Fig. 2 illustrats the cumulative proportions of mRS results. At the time of discharge, favorable outcomes (mRS score of 2 or less) were observed in 47.1% of PHH patients and 45.8% of PTH patients ($P=0.913$). Similarly, at the 2-year mark, favorable outcomes were noted in 82.4% of PHH patients and 72.9% of PTH patients ($P=0.318$). Median mRS scores were comparable between the groups at discharge ($P=0.760$) and at 2 years post-surgery ($P=0.578$).

The results of NIHSS scores (Fig. 3) showed no statistically significant difference at discharge from the hospital in either the PHH group ($P=0.868$) or the PTH group ($P=0.230$) compared to preoperative scores. However, NIHSS scores significantly decreased at the 2-year follow-up in both the PHH group ($P=0.002$) and the PTH group ($P=0.006$). Scores were similar between the groups at discharge ($P=0.230$) and at 2 years after shunt ($P=0.530$).

Furthermore, Evans index values were similar between the groups at discharge ($P=0.170$), with significant decreases noted postoperatively in both groups ($P<0.001$).

Regarding complications related to LPS implantation, as shown in Table 3, the overall incidence was comparable between the PHH and PTH groups ($P=0.991$). Over-drainage occurred in 20.6% of PHH patients

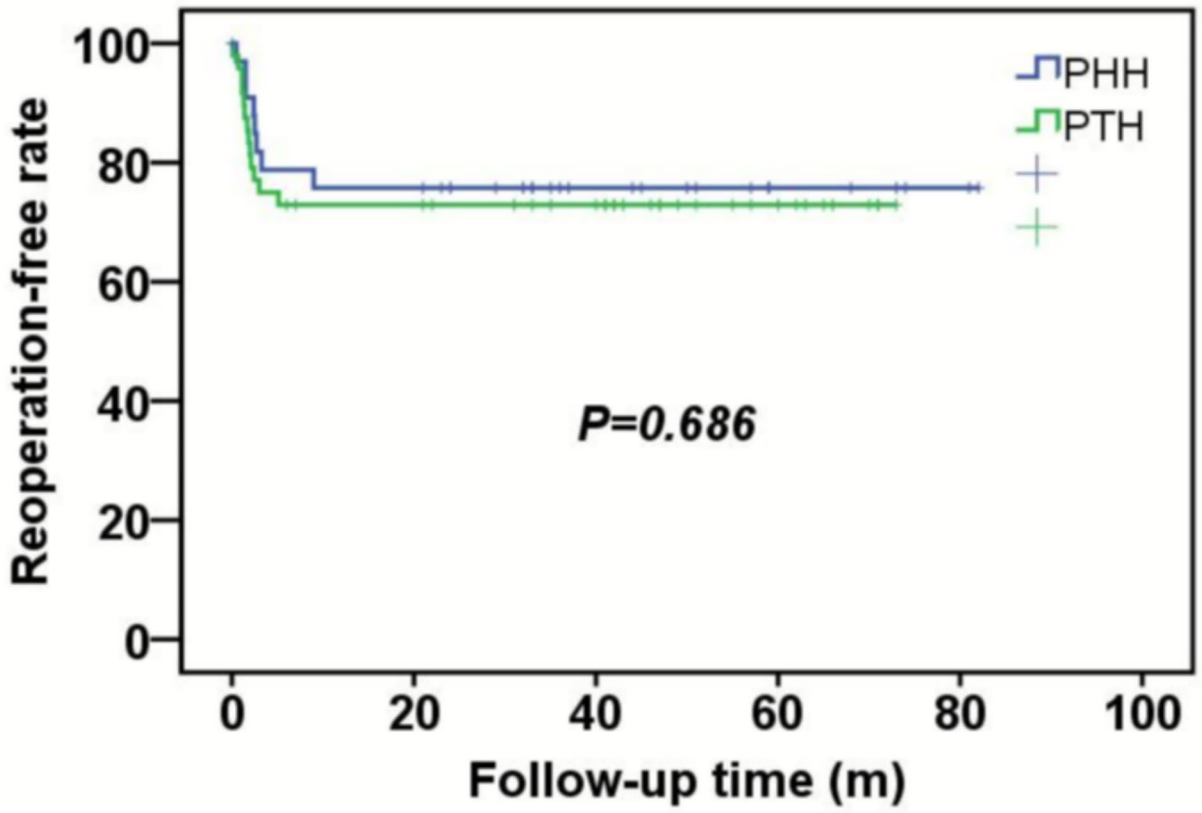

Fig. 1. The curve of reoperation-free rate.

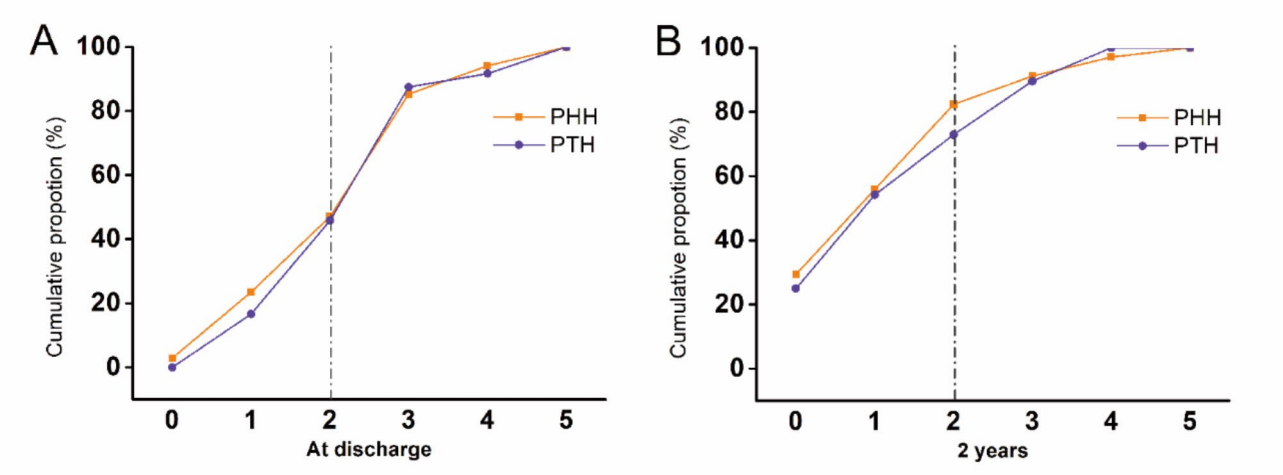

Fig. 2. The cumulative proportions of results on the modified Rankin's Scale (mRS). (**A**) at discharge from the hospital; (**B**) at 2 years after surgery. A score of 2 or less on the mRS (higher is worse) was defined as a favorable outcome.

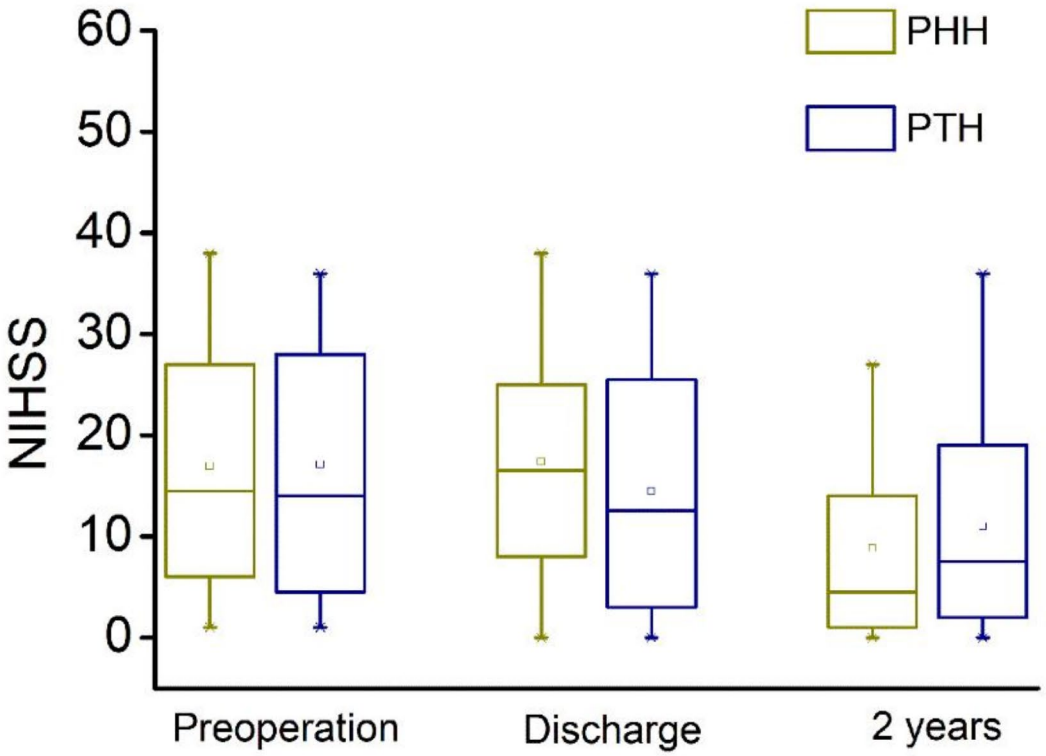

Fig. 3. The results of NIHSS before surgery, at discharge from hospital, and at 2 years after surgery.

	PHH	PTH	*P* value
No. of patients	34	48	
The overall complications, n (%)	12 (35.3%)	17 (35.4%)	0.991
Over-drainage	7 (20.6%)	8 (16.7%)	0.651
Inadequate drainage	4 (11.8%)	5 (10.4%)	0.847
Infection	2 (5.9%)	3 (6.3%)	0.945
Abdominal symptoms[†]	1 (2.9%)	2 (4.2%)	0.771
New epilepsy	0 (0%)	1 (2.1%)	0.397

Table 3. Shunting complications. [†]Abdominal symptoms include severe abdominal pain, diarrhea, and distention that are associated with shunt implantation.

and 16.7% of PTH patients. The incidence of specific complications, including inadequate drainage, infection, abdominal symptoms, and new epilepsy, did not differ significantly between the groups ($P > 0.05$).

Additionally, as shown in Table 2, patients in the PHH group had a shorter hospital stay post-LPS implantation compared with those in the PTH group (Median: 8.5 vs. 13, $P = 0.025$). No deaths related to shunt implantation occurred in either group.

Discussion

With the development of advanced shunt tubing and PPV, CSF shunting continues to be the first-line treatment, while nonoperative approaches have proven largely ineffective[13]. In general, the most commonly used type of CSF shunt is VPS while LPS surgery emerged as an effective alternative treatment for communicating hydrocephalus[5,14,15]. Compared with VPS, LPS avoids brain injury and is associated with a lower incidence of shunt infection[1]. LPS has been demonstrated to be an effective and safe treatment for patients with INPH in several studies. Kazui et al.[4,5] suggested that LPS could be the first option instead of VPS in the treatment of INPH based on a prospective, controlled trial considering about the minimal invasiveness. However, the

outcomes of LPS surgery for the treatment of PHH and PTH are not well studied. In a recent meta-analysis, the researchers found that there was no significant difference in the shunt failure rate between INPH patients who received VPS and those who received LPS treatment (VPS vs. LPS: 18% vs. 14%)[16]. The optimal surgical approach for the treatment of PHH remains a topic of debate among neurosurgeons. Currently, most scholars believe that VPS is the preferred method for treating patients with PHH There are few clinical studies providing limited evidence. Wang et al.[12] analyzed 56 patients with PHH or PTH treated by LPS in a retrospective trial, indicating that LPS surgery is equally as effective as the VPS with a low incidence of complications at 6 months. It is clear that this small number of patients and short-term follow-up do not reflect the entire spectrum of LPS implantation, and much is left to be learned with thorough and long-term evaluation in large data sets of patients with PHH or PTH. To provide a more comprehensive analysis we have designed a prospective, non-randomized controlled clinical trial to compare the clinical outcomes of LPS and VPS in the treatment of PHH and PTH, planning to recruit 150 patients[17]. Additionally, the incidence of over-drainage tends to be higher after LPS compared to VPS treatment. Existing literature reports an incidence as high as 21.1% for over-drainage following surgery in patients with communicating hydrocephalus treated with LPS[6].

In this study involving 82 patients with PHH or PTH, we found that LPS implantation could reduce the ventricular size at discharge and improve the neurological function at 2 years. Shunt reoperation was a common consequence following LPS, remaining a significant problem with such a diversion procedure. The rate of LPS reoperation is estimated to be 7-85.7% in various studies[1,11,18–20]. Our study showed the overall shunt reoperation rate was 25.6%, which was similar to previous studies. Besides, many patients underwent reoperation within the first 3 months after primary LPS implantation but with a continued risk of reoperation thereafter based on the curve of reoperation-free rate, which is in line with previous studies.

In this study, we hypothesized that patients with PHH and patients with PTH had equal outcomes after LPS surgery. In line with our hypothesis, the incidence of shunt reoperation, the percentage of patients who obtained a favorable outcome (a score of 2 or less on the mRS), neurological outcomes (corresponding to the results of NIHSS), and the incidences of complication following LPS implantation were similar between the 2 groups. Despite of the lack of statistical significance, PTH is associated with a higher incidence of shunt malfunction than PHH among patients with shunt reoperation.

The occurrence of shunt malfunction contributed to prolonged hospitalization following LPS implantation. Consequently, we observed a longer hospital stay in the PTH group compared to the PHH group. Notably, previous studies focusing on VPS treatment have suggested that patients with hydrocephalus secondary to intracranial hemorrhage may have a lower risk of shunt reoperation compared to those with hydrocephalus secondary to other causes[21]. This observation suggests potential differences in treatment outcomes based on the underlying etiology of hydrocephalus. However, the precise mechanism remains unknown. One possible explanation is that CSF shunt diverts the intraventricular blood products and alleviates hemorrhage-related inflammation with time resulting in an improvement of shunting outcomes[21,22].

In both groups, over-drainage emerged as the most common complication following LPS implantation. The siphon effect, particularly evident when patients assume a standing position, has been proposed as a significant contributor to over-drainage[11,23]. Nakajima M and their colleges[23] have explored the use of novel gravitational add-on valves with anti-siphon effects attached to PPV as a means to reduce the incidence of over-drainage post-LPS implantation. Furthermore, adjusting the initial pressure to its highest level and gradually lowering it by one interval at a time have been suggested strategies to mitigate over-drainage risk. Shunt infection represents another notable concern, with 2 patients (5.9%) in the PTH group and 2 patients (4.2%) in the PHH group experiencing shunt infection in our study. The reported incidence of shunt infection ranges from 0.5 to 10%, consistent with our findings[6]. The benefits and necessity of prophylactic antibiotic therapy remain unclear, particularly given the exogenous nature of the shunt system, necessitating further investigation in future studies. Furthermore, the current study did not observe severe adverse events post-LPS implantation, such as subdural hematoma, cerebral infarction, shunt tube migration, or death. These findings underscore the overall safety profile of LPS in our patient cohorts.

Limitations

We acknowledge several limitations in this study. The most significant is the subjective evaluation of symptom improvement, as no standardized scale exists for assessing symptoms specific to (PHH or PTH. Commonly used scales, like the INPH grading scale and Keifer's hydrocephalus scale, are not applicable to our cohorts, potentially introducing bias. Additionally, the retrospective, single-center design may limit generalizability. A randomized, controlled, multi-center trial with standardized symptom assessment tools would provide more robust evidence and help identify the optimal treatment approach for PHH and PTH.

Data availability

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

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Author contributions
TS and is responsible for providing critical review of concept, study design, investigation, and writing. SC and JW are involved in trial design, formal analysis, data curation, and revision of the manuscript. CY and KW are responsible for conceiving the idea for the present study, study design, writing, validation, and obtainning funding. All authors approve the final manuscript.

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Declarations

Competing interests
The authors declare no competing interests.

Institutional review board statement
The ethical review and approval were waived for this study by the Institutional Review Board and Ethics Committee of West China Hospital, Sichuan University. Since this study was retrospective.

Informed consent
Informed consent was obtained from all subjects involved in the study.

Additional information

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