Efficacy and Safety of Lumboperitoneal Shunt in the Treatment of All-Cause Communicating Hydrocephalus: Analysis of Risk Factors of Shunt Failure

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■ OBJECTIVE: **To analyze the outcomes of use of a lumboperitoneal shunt (LPS) to treat all-cause communicating hydrocephalus (ACCH).**

■ METHODS: **We analyzed the outcomes of adult patients with ACCH treated with an LPS between June 2015 and June 2018, using Keifer's hydrocephalus score (KHS), postoperative symptom improvement score (SIS), and the Evans index for 5 days after surgery. All patients were followed up to assess long-term outcomes and quality of life. Based on the follow-up data in shunt successful (SS) patients and shunt failure (SF) patients, multivariate analysis with binary logistic regression was used to identify risk factors for LPS failure.**

■ RESULTS: **A total of 71 eligible patients were included in this study. The KHS (mean, 8.31 ± 4.80 vs. 3.65 ± 3.08; $P < 0.001$) and Evans index (mean, 0.35 ± 0.05 vs. 0.28 ± 0.05; $P < 0.001$) were significantly improved following LPS. However, the overall incidence of complications was 40.8%. According to follow-up data, 18 patients (25.4%) failed; the most common reason for failure was catheter obstruction. The majority of patients obtain good prognosis with low level of RBCs counts in CSF ($P = 0.039$) and postoperative Evans index ($P = 0.046$) were statistically different between SS and SF group. The multivariate analysis identified elevated RBC count in CSF as a dependent risk factor for LPS failure (odds ratio, 24.111; 95% confidence interval, 2.611–222.629; $P = 0.005$).**

■ CONCLUSIONS: **Our findings indicate that LPS may be a promising option for the treatment of ACCH.**

INTRODUCTION

Communicating hydrocephalus, one of the most common diseases treated by neurosurgeons, is a disorder of cerebrospinal fluid (CSF) circulation with radiographic findings of ventricular dilatation in the absence of intraventricular obstruction occurring secondary to various intracranial diseases or idiopathically.[1-3] Currently, surgical CSF diversion with a ventriculoperitoneal shunt (VPS), lumboperitoneal shunt (LPS), or ventriculoarterial shunt (VAS) is the standard method for treating communicating hydrocephalus.[4-7] VPS has long been used as first-line treatment, whereas the application of VAS is limited owing to a high rate of severe complications after surgery.[8]

LPS, an important supplement to VPS, has attracted increasing research interest recently owing to several potential advantages over VPS, including no need to access ventricular cavities, avoidance of brain injury, and a lower risk of postoperative infection.[9,10] LPS has proven effective in treating idiopathic normal-pressure hydrocephalus and is now the most frequently performed surgical treatment for this disorder in Japan.[11] However, to the best of our knowledge, the efficacy and safety of using LPS to treat secondary communicating hydrocephalus, such as communicating hydrocephalus occurring secondary to traumatic brain injury and intracranial hemorrhage, remains controversial.

Key words
- Communicating hydrocephalus
- Efficacy
- Lumboperitoneal shunt
- Risk factors
- Safety

Abbreviations and Acronyms
ACCH: All-cause communicating hydrocephalus
CI: Confidence interval
CSF: Cerebrospinal fluid
ELD: External lumbar drainage
GOS: Glasgow Outcome Scale
ICH: Intracranial hemorrhage
KHS: Keifer's hydrocephalus score
LPS: Lumboperitoneal shunt
OR: Odds ratio
SF: Shunt failure
SIS: Symptom improvement score
SS: Shunt successful
TT: Tap test
VAS: Ventriculoarterial shunt
VPS: Ventriculoperitoneal shunt

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In the present study, we analyzed patients with ACCH treated by LPS in our department between June 2015 and June 2018 to determine the long-term outcomes of LPS in the treatment of all-cause communicating hydrocephalus (ACCH). Baseline characteristics, preoperative clinical features, symptomatic and imageologic improvement, and postoperative complications following shunt implantation were synchronously investigated. All patients were followed up after shunt implantation to assess outcomes and quality of life, including shunt failure rate and modified Rankin scale (mRS) score. At follow-up, risk factors for LPS failure were identified through comparison of shunt-successful (SS) patients and shunt-failed (SF) patients and multivariate analysis using binary logistic regression.

MATERIALS AND METHODS

Study Design

We retrospectively analyzed patients with communicating hydrocephalus treated by LPS between June 2015 and June 2018 in our department. Patients age <18 years, those with severe disorders of consciousness disorders before shunt implantation (Glasgow Coma Scale [GCS] score <9), and those lost to follow-up were excluded from our study. Shunt catheters with programmable pressure valve were obtained from Sophysa (Orsay, France). Written informed consent was obtained from all participants.

Perioperative Conditions

Patient information, including age, sex, etiology, time from onset to operation, time from operation to follow-up, and previous shunt history, was obtained from the medical record. Preoperative clinical features, including clinical manifestation, GCS score, Evans index, and CSF parameters, were synchronously investigated. To determine improvement of symptoms and ventricles, we considered Keifer's hydrocephalus score (KHS),[12] symptomatic improvement score (SIS), and the Evans index at the time of admission and again at 5 days after surgery. KHS is determined on a scale of 1–5 in 5 areas: gait disturbance, mental disorder, urinary incontinence, headache, and vertigo. The 5 scores are summed; the lower the score, the better the improvement. The SIS score, ranging from 0 to 10, evaluates symptoms according to patients' self-assessment of symptomatic improvement, with higher score indicating better improvement (0–2, poor; 3–5, satisfactory; 6–8, good; 9–10, excellent). We also investigated postoperative complications and hospital length of stay.

Postoperative Follow-Up

All patients were followed up by telephone interview, outpatient visits, or letter to investigate long-term shunt outcomes, including shunt success or failure, Glasgow Outcome Scale (GOS), and mRS. In According to previous study,[10,11] shunt failure was defined as the occurrence of clinical or radiologic signs or symptoms of shunt obstruction, infection, or malfunction requiring shunt revision after LPS, or hydrocephalus-associated death. Shunt success was defined as the absence of shunt failure or good control of hydrocephalus without revision.

Analysis of Risk Factors

According to the results of follow-up, we divided the patients into 2 groups, shunt successful (SS) and shunt failure (SF). We compared the SS and SF groups in terms of age, sex, etiology, previous shunt history, duration of follow-up, symptoms, duration of symptoms, GCS score, Evans index, CSF glucose, CSF chlorine, CSF nucleated cells, CSF RBCs, hospital length of stay, and postoperative complications. We then used binary logistic regression analysis focusing on these variables to identify the risk factors for LPS failure.

Table 1. Baseline Characteristics of Patients Treated by LPS

Characteristic	Total
Number of patients	71
Age (years), mean ± SD	52.26 ± 15.88
Sex, n (%)	
Male	52 (73.2)
Female	19 (26.8)
Etiology, n (%)	
Posttraumatic	30 (42.3)
Hemorrhagic	31 (43.7)
Infectious	2 (2.8)
Idiopathic	8 (11.2)
Time from onset to operation (days), median (range)	28 (2–730)
History of previous shunt, n (%)	
Yes	10 (10.8)
No	83 (89.2)
Time from operation to follow-up (months), mean ± SD	16.82 ± 11.99

LPS, lumboperitoneal shunt.

Statistical Analysis

All data were analyzed using SPSS version 19 (IBM, Armonk, New York, USA). The Kolmogorov–Smirnov test was first used to determine the normality of quantitative data. Continuous data

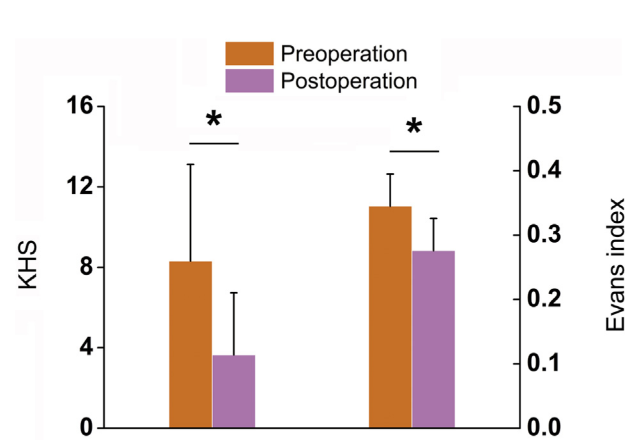

Figure 1. Postoperative improvement in symptoms and imaging features. $^*P < 0.001$.

Table 2. Postoperative Recovery Following LPS Use

Parameter	Value
SIS (%), median (range)	7 (0—10)
Outcome of SIS, n (%)	
Excellent (SIS 9—10)	17 (23.9)
Good (SIS 6—8)	31 (43.7)
Satisfactory (SIS 3—5)	19 (26.8)
Poor (SIS 0—2)	4 (5.6)
Occurrence of complications, n (%)	
Yes	29 (40.8)
No	42 (59.2)
Complications, n (%)	
Overdrainage	
Yes	15 (21.1)
No	56 (78.9)
Inadequate drainage	
Yes	8 (11.3)
No	63 (88.7)
Infection	
Yes	10 (14.1)
No	61 (85.9)
Abdominal discomfort*	
Yes	4 (5.6)
No	67 (94.4)
Epilepsy	
Yes	1 (1.4)
No	70 (98.6)
Postoperative length of stay (days), median (range)	10 (4—139)

LPS, lumboperitoneal shunt; SIS, symptomatic improvement score.
*Abdominal discomfort was defined as abdominal distension, pain, discomfort, or other symptoms that related to shunt implantation.

following normal and nonnormal distributions are expressed as mean ± standard deviation (SD) and median (range), respectively, while categorical variables are expressed as number (percentage). The independent-samples t test was used to compare preoperative and postoperative KHS and Evans index scores. In comparisons of the SS and SF groups, the independent-samples t test was used for age, Evans index, GCS glucose, and CSF chlorine; the Wilcoxon rank-sum test was used for duration of follow-up, duration of symptoms, GCS score, CSF nucleated cells, CSF RBCs, and hospital length of stay; and the χ^2 test (or Fisher's exact test when appropriate) was used for sex, etiology, previous shunt history, symptoms, and complications. A P value <0.05 was considered to indicate statistical significance. In the binary logistic regression analysis, variables with $P < 0.1$ in univariate analysis were selected

Table 3. Outcomes at Follow-Up

Outcome	Value
Time from operation to follow-up (months), mean ± SD	16.82 ± 11.99
Shunt success, n (%)	53 (74.6)
Shunt failure, n (%)	18 (25.4)
Catheter obstruction	9 (50.0)
Infection	5 (27.8)
Overdrainage*	2 (11.1)
Catheter exposure	2 (11.1)
GOS, median (range)	4 (1—5)
mRS, median (range)	2 (0—5)

GOS, Glasgow Outcome Scale; mRS, modified Rankin Scale.
*Two patients with refractory low-pressure headache underwent shunt revision.

for further multivariate analysis, in which a $P < 0.05$ was considered significant.

RESULTS

Patients

Between June 2015 and June 2018, we treated 106 patients diagnosed with communicating hydrocephalus using an LPS. Twenty-two patients without preoperative CSF data, 9 patients with severely disordered consciousness, 2 patients lost to follow-up, and 2 patients age <18 were excluded from the study. The remaining of 71 eligible patients, 52 males and 19 females, were included. The mean age was 52.26 years, and the mean follow-up time was 16.82 months. No hydrocephalus-associated deaths were observed during follow-up. Only 10 patients (10.8%) had a previous history of shunt implantation. The patients' baseline characteristics are summarized in Table 1. patients suffered from

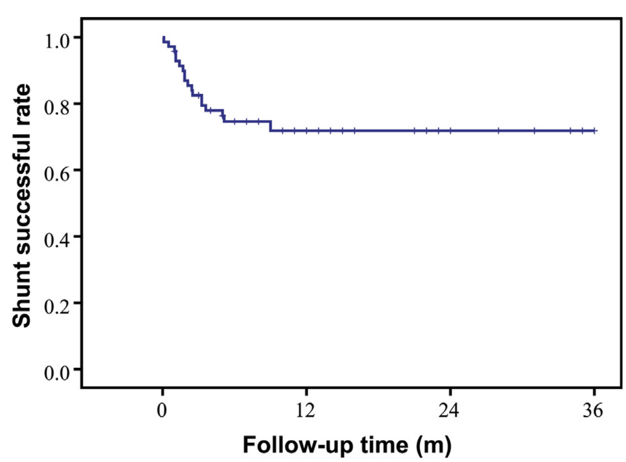

Figure 2. The shunt successful rate curve using Kaplan-Meier survival analysis.

Table 4. Characteristics of the Shunt Successful and Shunt Failed Groups

Characteristic	Shunt Successful Group (N = 53)	Shunt Failed Group (n = 18)	*P* Value
Age, y, mean ± SD	52.1 ± 17.0	52.5 ± 13.0	0.927
Sex, n (%)			0.911*
Male	39 (73.6%)	13 (72.2%)	
Female	14 (26.4%)	5 (27.8%)	
Etiology, n (%)			0.385
Posttraumatic	20 (37.7%)	10 (55.6%)	
hemorrhagic	26 (49.1%)	5 (27.8%)	
Infectious	1 (1.9%)	1 (5.6%)	
Idiopathic	6 (11.3%)	2 (11.1%)	
Time from operation to follow-up (months), mean ± SD	17.89±12.52	13.67±10.37	0.167
Previous shunt history, n (%)			0.819*
Yes	7 (13.2%)	2 (11.1%)	
No	46 (86.8%)	16 (88.9%)	
Symptoms, n (%)			
Headache	17 (32.1%)	7 (38.9%)	0.598
Gait disturbance	18 (34.0%)	8 (44.4%)	0.425
Mental disorder	14 (26.4%)	4 (22.2%)	0.726*
Urinary incontinence	1 (1.9%)	1 (5.6%)	0.420*
Vertigo	9 (17.0%)	4 (22.2%)	0.622*
Time from onset to operation (days), median (range)	28 (3—365)	25 (2—730)	0.610
Preoperation			
GCS, median (range)	12 (4—16)	13 (5—15)	0.929
Evans index, mean ± SD	0.35±0.05	0.34 ±0.04	
CSF parameters			
Protein, g/L, mean ± SD	0.55±0.36	1.05 ± 1.67	0.229
Nucleated cells, $\times 10^6$/L	0 (0—486)	2.5 (0—210)	0.069
RBCs, $\times 10^6$/L	0 (0—5000)	27.5 (0—1400)	0.037†
Glucose, mmol/L, mean ± SD	3.30 ± 0.75	3.51 ± 1.11	0.394
Chlorine, mmol/L, mean ± SD	123.82 ± 5.02	124.82 ± 9.25	0.667
Postoperation			
Length of stay (days), median (range)	7.5 (4—81)	11 (5—139)	0.224
One or more complications after LPS, n (%)			0.845
Yes	22 (41.5)	7 (38.9)	
No	31 (58.5)	11 (61.1)	

OR, odds ratio; CI, confidence interval; GCS, Glasgow Coma Scale; CSF, cerebrospinal fluid; RBCs, red blood cells; LPS, lumboperitoneal shunt.
*Fisher's exact test.
†$P < 0.05$.

communicating hydrocephalus was secondary to traumatic brain injury in 30 patients (42.3%) and secondary to intracranial hemorrhage in 31 patients (43.7%).

Short-Term Outcomes

We evaluated short-term outcomes after LPS by analyzing changes in the KHS, Evans index, and SIS, corresponding to improvement of symptoms and ventricular function. The KHS (8.31 ± 4.80 preoperative vs. 3.65 ± 3.08 postoperative; $P < 0.001$) and Evans index (0.35 ± 0.05 vs. 0.28 ± 0.05; $P < 0.001$) were significantly improved at 5 days after LPS implantation (Figure 1). The median SIS was 7; SIS was classified as good in 31 patients (43.7%), excellent in 17 patients (23.9%), satisfactory in 19 patients (26.8%), and poor in 4 patients (5.6%).

The patients treated with LPS experienced numerous complications, however. The overall incidence of complications was 40.8% (19 patients). The most frequent complication was overdrainage (OD; 15 patients; 21.1%), followed by infection (10 patients; 14.1%) and inadequate drainage (8 patients; 11.3%). Only 4 patients (5.6%) experienced abdominal discomfort, and 1 patient (1.4%) experienced seizure relating to shunt placement (Table 2). The median postoperative length of stay was 10 days (range, 4—139 days).

Long-Term Outcomes

Eighteen patients (25.4%) failed LPS, necessitating shunt revision, as shown in Table 3. The most common reason for revision was catheter obstruction (9 patients; 50.0%). In addition, 5 patients (27.8%) failed due to infection, 2 (11.1%) failed due to catheter exposure, and 2 (11.1%) experienced refractory low-pressure headache. A successful shunt rate curve calculated using the method of Kaplan-Meier (Figure 2) shows that all patients needing revision received it within 12 months. The investigation of quality of life showed the median of GOS score of 4 and a median mRS score of 2.

Analysis of Risk Factors

RBC counts in CSF ($P = 0.039$) and postoperative Evans index ($P = 0.046$) were statistically significantly different between the SS and SF groups (Table 4). However, there was no significant between-group difference in age ($P = 0.927$), sex ($P = 0.911$), etiology of hydrocephalus ($P = 0.385$), time from operation to follow-up

(P = 0.167), prior shunt history (P = 0.819), time from onset to operation (P = 0.610), preoperative GCS (P = 0.929), preoperative CSF protein concentration (P = 0.229), preoperative nucleated cell counts (P = 0.069), or the presence of complications following LPS implantation (P = 0.845).

Multiple-Factor Analysis. Binary logistic regression was used to perform multiple-factor analysis. The results are presented in Table 5. Variables with P < 0.1 in univariate analysis, including elevated nucleated cell counts in CSF (>10 × 10^6/L; odds ratio [OR], 4.800; 95% confidence interval [CI], 1.251–18.421; P = 0.022), elevated RBC counts in CSF (>100 × 10^6/L; OR, 3.111, 95% CI, 0.948–10.209; P = 0.061), and postoperative Evans index (OR, 0; 95% CI, 0–2.496; P = 0.066), were first selected for further multivariate analysis. Other factors highly suspected to be related to shunt failure were not of statistical significance, including age (OR, 1.001; 95% CI, 0.968–1.036; P = 0.935), post-traumatic hydrocephalus (OR, 2.062; 95% CI, 0.698–6.091; P = 0.190), previous shunt history (OR, 0.821; 95% CI, 0.154–4.369; P = 0.818), preoperative GCS score (OR, 1.012; 95% CI, 0.846–1.210; P = 0.897), and elevated CSF protein (>1.0 g/L; OR, 3.013; 95% CI, 0.792–11.464; P = 0.106). Further multivariate analysis identified elevated RBC count in CSF (>100 × 10^6/L) as a dependent risk factor for shunt failure (OR, 24.111; 95% CI, 2.611–222.629; P = 0.005). However, postoperative Evans index (OR, 0.001; 95% CI, 0–4862.938; P = 0.371) and elevated nucleated cell counts in CSF (OR, 4.800; 95% CI, 0.397–58.013; P = 0.217) were not associated with LPS failure.

DISCUSSION

LPS has long been demonstrated to be effective and safe in the treatment of idiopathic normal-pressure hydrocephalus, showing several potential advantages over VPS.[9,13] Our present work suggests the viability of LPS as a potential option to treat ACCH. Most of our patients treated by LPS showed considerable improvement in both symptoms and ventricular size. On the SIS, 48 patients (67.6%) reported excellent or good symptomatic improvement, and only 4 patients (5.6%) reported a poor outcome. In line with these SIS findings, 48 patients (64.8%) with high Evans index (>0.3) before shunt insertion drop to under 0.3, and 59 patients (83.1%) showed symptomatic improvement reflected in the KHS at 5 days after LPS implantation. After implantation, the majority of patients had a good prognosis according to their GOS and mRS scores.

Table 5. Binary Logistic Regression Analysis of Risk Factors for Shunt Failure Following LPS

	Univariate Analysis			Multivariate Analysis		
Parameter	OR	95% CI	*P* Value	OR	95% CI	*P* Value
Age	1.001	0.968–1.036	0.935			
Male sex	1.124	0.343–3.683	0.847			
Post-traumatic hydrocephalus	2.062	0.698–6.091	0.190			
Duration of follow-up	0.969	0.924–1.017	0.203			
Previous shunt history	0.821	0.154–4.369	0.818			
Duration of symptoms	1.002	0.998–1.007	0.335			
Preoperation						
GCS	1.012	0.846–1.210	0.897			
Evans index	0.187	0–24,010.428	0.780			
CSF parameters						
Protein >1.0 g/L	3.013	0.792–11.464	0.106			
Nucleated cells >10 × 10^6/L	4.800	1.251–18.421	0.022*	4.800	0.397–58.013	0.217
RBCs >100 × 10^6/L	3.111	0.948–10.209	0.061*	24.111	2.611–222.629	0.005†
Glucose	1.320	0.701–2.488	0.390			
Chlorine	1.025	0.943–1.113	0.561			
Postoperation						
Length of stay	0.992	0.964–1.021	0.583			
Improved Evans index	0	0–2.496	0.066*	0.001	0–4862.938	0.371
Postoperative pressure adjustment	1.059	0.340–3.301	0.922			

OR, odds ratio; CI, confidence interval; GCS, Glasgow Coma Scale; CSF, cerebrospinal fluid; RBCs, red blood cells.
*Variables with $P < 0.1$ were selected for multivariate analysis.
†$P < 0.05$.

Nonetheless, patients undergoing LPS implantation face numerous potential complications. OD is the most common complication following LPS, leading to low-pressure syndrome. A siphon effect occurring when the patient stands has been closely associated with OD.[14] Use of an antisiphon device attached to a programmable pressure valve has proven effective in avoiding OD.[15] Although there was a high incidence of complications in our cohort, shunt-associated death and some previously reported severe complications[13] were not observed.

Shunt failure, as an unacceptably common outcome, is another concern following LPS. The reported incidence of shunt revision ranges from 7% to 85.7%.[11] Miyajima et al.[16] suggested a higher rate of shunt failure requiring revision and less efficacy in patients with an LPS compared with those with a VPS at 1 year after shunt placement. In our cohort, 18 patients (25.4%), most of whom failed within 3 months owing to shunt obstruction, failed and underwent shunt revision.

Finding ways to decrease the risk of LPS failure is attracting increasing research interest. The path to a favorable shunt outcome begins with evaluation of the patient's suitability for shunt implantation.[12] Preoperative supplementary tests, such as the tap test (TT) and external lumbar drainage (ELD), can help determine a patient's suitability and thus decrease the risk of failure. ELD, first reported by Haan and Thomeer,[17] has been shown to be suitable for patients with a negative TT. An increasing number of studies have shown that a positive response to TT or ELD suggests a patient's suitability for treatment with an LPS.[17] However, the definition of positive response to TT or ELD remains controversial. The majority of neurosurgeons would choose shunt implantation if patients showed improvement of symptoms, especially in gait disorders. Symptom improvement may be seen after TT or ELD even with no change in the ventricles.

In addition, analyzing the risk factors for LPS failure may help guide exclusion of high-risk patients before surgery. Although a number of studies have aimed to determine risk factors of shunt failure following VPS, there are little published data on risk factors for LPS failure. Here, for the first time, we have analyzed the risk factors for LPS failure and identified elevated RBC count in CSF as a dependent risk factor. There is a persistent belief that high protein level or cell count in CSF at the time of shunt implantation might increase the risk of shunt failure, but evidence to support this is poor.[18] Nonetheless, an increasing number of studies have found no statistically significant associations between shunt failure and CSF parameters.[19-21] Further research is needed to obtain a holistic view of changes in the CSF system before and after shunt implantation and the mechanism(s) underlying the significance of CSF parameters in shunt outcome. In addition, some variables previously reported to be associated with VPS failure—including age, previous shunt history, time from onset to operation, and etiology of hydrocephalus[22-25]—apparently have no relevance to LPS outcomes according to our data.

Limitations

This study has several limitations. First, we analyzed patient outcomes based on a single-institution retrospective study in the presence of possible systematic bias and variation. Second, our sample size is small, considering that more than 500 patients with communicating hydrocephalus are admitted to our department each year. Considering that LPS is still not as widely used as VPS, the current work is a big population study while comparing other published LPS-related research.

CONCLUSION

In conclusion, our data show that LPS is a promising option for treating ACCH. Most of the patients treated with LPS implantation had a good prognosis. Our binary logistic regression analysis suggests that elevated RBC count in CSF is a dependent risk factor for LPS failure.

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