

Clinical Article

A Comparative Result of Ventriculoperitoneal Shunt, Focusing Mainly on Gravity-Assisted Valve and Programmable Valve

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Objective : Despite rapid evolution of shunt devices, the complication rates remain high. The most common causes are turning from obstruction, infection, and overdrainage into mainly underdrainage. We investigated the incidence of complications in a consecutive series of hydrocephalic patients.

Methods : From January 2002 to December 2009, 111 patients underwent ventriculoperitoneal (VP) shunting at our hospital. We documented shunt failures and complications according to valve type, primary disease, and number of revisions.

Results : Overall shunt survival time was 268 weeks. Mean survival time of gravity-assisted valve (GAV) was 222 weeks versus 286 weeks for other shunts. Survival time of programmable valves (264 weeks) was longer than that of pressure-controlled valves (186 weeks). The most common cause for shunt revision was underdrainage (13 valves). The revision rate due to underdrainage in patients with GAV (7 of 10 patients) was higher than that for other valve types. Of 7 patients requiring revision for GAV underdrainage, 6 patients were bedridden. The overall infection rate was 3.6%, which was lower than reported series. Seven patients demonstrating overdrainage had cranial defects when operations were performed (41%), and overdrainage was improved in 5 patients after cranioplasty.

Conclusion : Although none of the differences was statistically significant, some of the observations were especially notable. If a candidate for VP shunting is bedridden, GAV may not be indicated because it could lead to underdrainage. Careful procedure and perioperative management can reduce infection rate. Cranioplasty performed prior to VP shunting may be beneficial.

KEY WORDS : Hydrocephalus · Gravity-assisted valve · Survival time · Complication · Shunt.

INTRODUCTION

Ventriculoperitoneal (VP) shunt surgery is not a technically demanding neurosurgical procedure. Nevertheless, despite the rapid evolution of shunt devices, the procedure presents many pitfalls and complications that sometimes require revision. Recently, various shunt valves with different underlying design concepts have been developed. However, the decision regarding which valve to use in the treatment of a specific patient is based mainly on clinical factors and still depends

on the experience of the surgeon.

Adjustable shunt valves and gravitational (gravity-assisted) valve (GAV) are among recent developments. GAV is designed to minimize overdrainage, especially the problem of siphoning, as well as underdrainage^{8,21,22,28}. Numerous clinical trials have supported the conclusion that gravitational valves reduce by half the rate of occurrence of overdrainage, to 3-5%^{2,4,9,13,15,16,26}, while the risk of underdrainage is increased^{6,11}. In the present study, overall shunt survival time of various shunt valves and the complications related to each were analyzed, prompting us to suggest guidance in order to avoid shunt-related complications.

MATERIALS AND METHODS

Patient population

Over a period of 8 years, 126 shunt surgeries were per-

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formed at our hospital. Patients with a follow-up period of less than 4 weeks (9 patients), those with incomplete medical records (2 patients), and 4 patients who died within 4 weeks of surgery were excluded. Therefore, 111 patients were finally enrolled in this study, and data were collected to document the study's primary endpoint. We retrospectively reviewed a database containing information on patients with hydrocephalus treated between January 2002 and the end of December 2009. This database included all patients who had undergone VP shunt insertion at our center. Clinical and radiological findings, including information about patients' sex and age, the cause of the hydrocephalus, the type of valve used, complications encountered, the number of revisions, radiological findings, neurological changes, and the duration of follow-up were recorded. All patients who experienced complications were identified, and their medical records were retrospectively reviewed.

Shunt failure and complications

We defined shunt failure as a lack of function or insufficient function, a proven evidence of malfunction on brain shuntogram, or significant complications necessitating shunt revision. Once a shunt was revised, it had reached its "survival endpoint."

Overdrainage was defined in 2 ways : clinical overdrainage was identified independent of any radiological findings by clinical symptoms such as headache or nausea that occurred

in the erect position but that promptly disappeared in the supine position. Radiological overdrainage symptoms included subdural hygroma exceeding 3 mm in width, subdural hematoma, or slit-like ventricles¹³.

Underdrainage was diagnosed if a patient had an unfavorable outcome on the Homburg Hydrocephalus Scale (HHS) or if they exhibited secondary neurological deterioration and enlargement of the ventricles compared with the preoperative state on radiological studies such as computerized tomography (CT) or magnetic resonance imaging (MRI)¹³. We applied the HHS (Table 1) to identify unfavorable clinical outcomes¹⁴; however, in many cases, medical records were insufficient to apply this scale, so its complete application was not achieved.

Radiologic findings

The radiological effects of shunt treatment were determined by comparing the diagonal ventricular volume and the Evans ratio in the preoperative CT scan, early postoperative CT scans (< 6 weeks), and late postoperative CT scans (> 6 weeks)¹⁸.

Statistical analysis

Statistical analyses were performed by using the chi-square test and Fisher's exact test. Survival analyses were performed using the Kaplan-Meier method, with statistical significance being evaluated with the log-rank test. The hazard ratio was calculated by the Cox proportional model. A *p* value of less than 0.05 was considered to be significant. Statistical computations were performed with commercially available software (SPSS, version 12 for Windows, SPSS Inc., Chicago, IL, USA).

RESULTS

Demographic characteristics

Mean patient age at implantation was 57 ± 13.59 years (range, 16-77). There was a slight preponderance of males (70 patients, 63%). The most common cause for shunt surgery was hemorrhage (62 patients, 55%), including subarachnoid hemorrhage (43 patients, 39%), and intracerebral hemorrhage (ICH) or intraventricular hemorrhage (IVH) (18 patients, 16%). Posttraumatic hydrocephalus followed as a secondary cause (35 patients,

Table 1. Homburg Hydrocephalus Scale

Category and score	Symptom
Mental	0 No clinical detracton
	1 Concentration disorder, forgetfulness
	3 Apathy, oriented only in parts
	5 Completely disorientated, skill disorder
Gait	0 No clinical detracton
	1 Gait disorder in special tests
	2 Atactic, wide-based gait, but secure
	4 Walking is difficult, only with crutches (or similar) possible
	5 Only a few steps with help of other person
	6 Bedridden
Incontinence	0 None
	1 Urge incontinence
	3 Temporary incontinence (nocturnal)
	4 Permanent incontinence
	6 Urine and fecal incontinence
Headache	0 None
	1 Intermittent headache, permanent slight to moderate headache*
	4 Permanent severe headache†
Vertigo	0 None
	1 Intermittent vertigo (e.g., under stress or spontaneously)
	2 Permanent vertigo

*Slight-moderate headache : value assigned on the visual analog scale < 6, †Severe headache : value assigned on the visual analog scale ≥ 6

31.5%).

Seven different types of valves were used : the GAV (Aesculap-Miesthke, Tuttlingen/Postdam, Germany, 5/30, 5/40) in 53 patients, a programmable valve (ProGAV) with a gravitational unit (Aesculap-Miesthke, Tuttlingen/Postdam, Germany, 0-20/20, 3 patients), ProGAV without a gravitational unit (Aesculap-Miesthke, Tuttlingen/Postdam, Germany, 0-20/0, 9 patients), a Codman Hakim programmable valve (CHPV, Codman & Shurtleff Inc., USA) in 14 patients, strata valve (Medtronic Neurosurgery, Goleta, CA, USA) in 10 patients, and other types in 22 patients, including Pudenz (Heyer-Schulte® Pudenz Flushing valves, Integra™), and Novus valves (Novus™ valve system, Integra™). Demographics and clinical features of the enrolled patient population are shown in Table 2.

Survival time of VP shunts

Mean valve survival time was analyzed according to primary causative factor (trauma or posthemorrhagic) and type of valve (GAV or programmable). Overall shunt survival time was 268 weeks. Survival times in the trauma and posthemorrhagic groups were 223 weeks and 283 weeks, respectively ($p = 0.208$). The mean survival time for GAV shunts was 222 weeks compared with 286 weeks for any other shunt type ($p = 0.375$). The survival time of programmable valves (264 weeks) was longer than that of pressure-controlled-type valves (186 weeks) ($p = 0.377$) (Fig. 1). The hazard ratio was calculated using the Cox proportional model; results are summarized in Table 3.

Shunt failures and complications

Complications of clinical course were recorded during regular follow-up examinations, or if indicated, at unscheduled follow-ups. During the period covered by the study, 19 valves in 15 patients were revised, thereby meeting the criteria for shunt failure endpoint. The most common cause for shunt revision was underdrainage in 13 patients ($p = 0.167$), followed by proximal obstruction in 3 patients, infection in 2 patients, and overdrainage in 1 patient (Fig. 2). The overall shunt failure rate was 16.2%. The revision rate due to underdrainage in patients with GAV (7 revisions out of 10 patients) was higher than that for other valve types ($p = 0.344$). Revisions for other shunt types were as follows : ProGAV in 1 patient, CHPV in 1 patient, Novus in 2 patients, and Pudenz in 1 patient. Of seven patients requiring revision because of underdrainage in a GAV, 6 patients were bedridden ($p = 0.125$). Valve inclination in all GAV patients was $5.50^\circ \pm 12.40^\circ$ (-24.5° to 38.5°) relative to the vertical.

Complications not requiring revision occurred in 22 patients and included overdrainage (20 patients), infection (1

patient), and valve exposure (1 patient). Developed complications and number of revisions in each shunt system were summarized in Fig. 3.

Seven patients demonstrating overdrainage exhibited a cranial defect when shunt surgery was performed (41%, $p = 0.629$), and 5 patients demonstrating overdrainage (3 with GAV and 2 with ProGAV) improved after cranioplasty ($p = 0.093$). Two patients improved radiologically after additional valve pressure adjustment but deteriorated neurologically.

Table 2. Demographics and clinical features of enrolled patients

Clinical characteristics	
No. of patients enrolled	111
Age at implantation	
Median	70
Mean	57 ± 13.59
Minimum	16
Maximum	77
Sex	
Male	70
Female	41
Hydrocephalus cause	
Idiopathic NPH	5
Post hemorrhagic	
ICH, IVH	18
SAH	43
Post traumatic	35
Others (tumor, LOVA, TB, etc.)	10
Implantation	111
First implantation	92
Revision	19
1 time	12
2 times	2
> 3 times	1
Insertion location	
Kocher's point	
Right	80
Left	26
Others	5
Keen's point	3
Bilateral Kocher's point	1
Unknown	1
Type of valve	
Gravity assisted	
ProGAV	3
GAV	52
Programmable	
ProGAV (gravitational)	12 (3)
Codman Hakim	14
Strata	10
Others	22

NPH : normal-pressure hydrocephalus, ICH : intracerebral hemorrhage, IVH : intraventricular hemorrhage, SAH : subarachnoid hemorrhage, LOVA : Long-standing overt ventriculomegaly in adults, TB : tuberculosis, ProGAV : programmable valve gravity-assisted valve, GAV : gravity-assisted valve

We also adjusted pressure in 11 overdrainage patients. The number of adjustments ranged from 3 to 10 times (mean, 7 times), and the interval extended from 3 days to 2 weeks (mean, 6.5 days). Only 3 patients improved both radiologically and neurologically after adjustment; 1 of 5 patients with ProGAV and 2 of 6 patients with CHPV improved. One patient did not improve either neurologically or radiologically and experienced worsening subdural hygroma. One patient improved neurologically just after VP shunting but then experienced overdrainage; following pressure adjustment to correct the overdrainage, she suffered neurological

deterioration. One patient required surgical drainage for chronic subdural hematoma. Five other patients requiring pressure adjustment improved radiologically but deteriorated neurologically following adjustment.

DISCUSSION

Since Foltz reported improved outcomes in hydrocephalic children by using ventriculoatrial shunts in the 1960s, the most popular management of hydrocephalus has been cerebrospinal (CSF) diversion via shunt¹⁰. Although much pro-

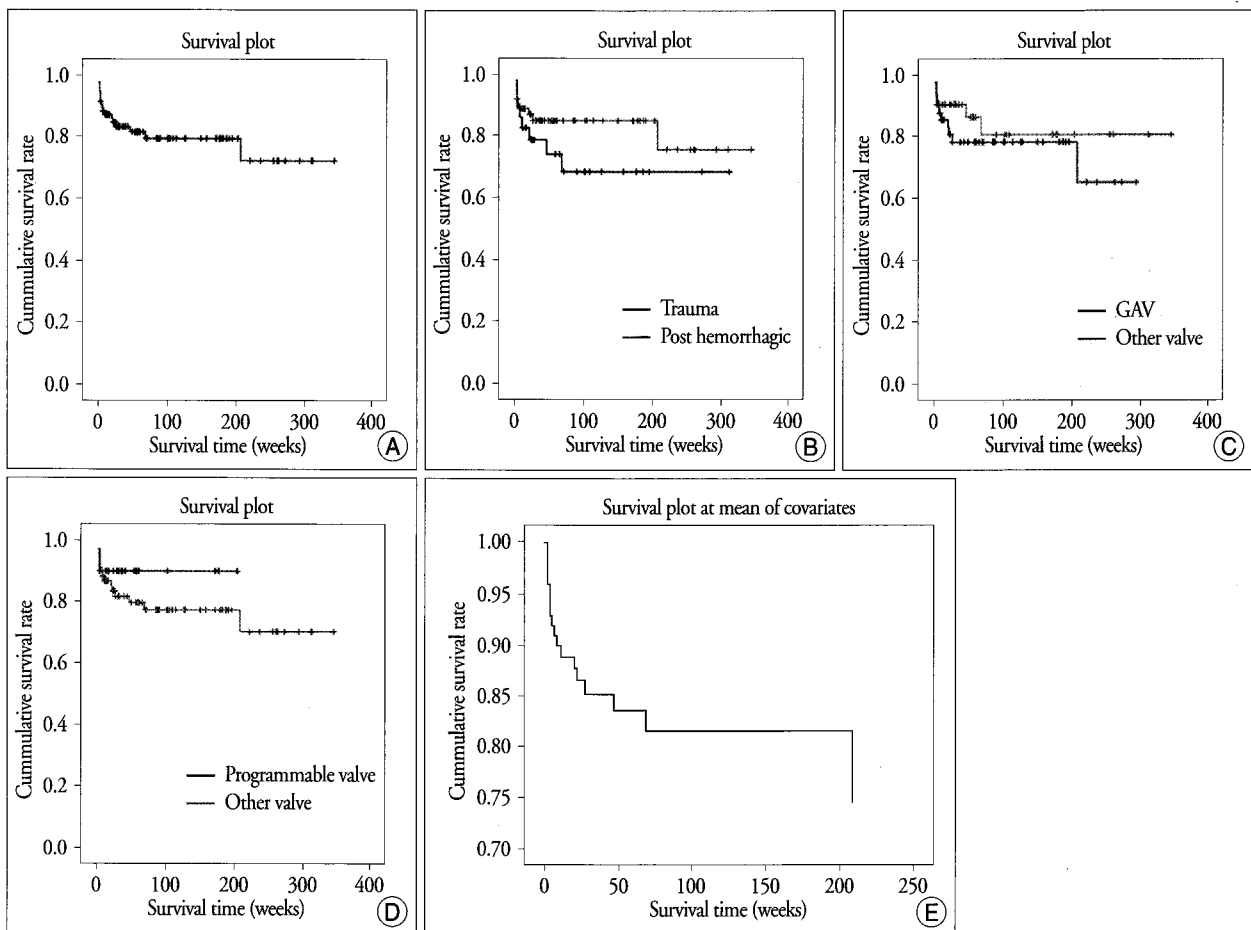


Fig. 1. A : Survival plot of a ventriculoperitoneal (VP) shunt. B : Survival plot of primary causes. C : Survival plot of gravity-assisted valve (GAV). D : Survival plot of programmable valve (ProGAV). E : Cox proportional hazard model.

Table 3. Hazard ratio according to each variables using the Cox proportional model

Variables	B	Chi-square	Hazard ratio	p-value	95% CI for hazard ratio	
					Lower	Upper
Trauma	0.267	0.108	1.305	0.742	0.267	6.387
Posthemorrhagic	-0.043	0.003	0.958	0.957	0.197	4.652
Sex	-0.245	0.192	0.783	0.661	0.261	2.343
Age	0.020	0.855	1.020	0.355	0.978	1.063
Programmable valve	-0.447	0.259	0.640	0.611	0.114	3.583
GAV	0.264	0.201	1.302	0.654	0.412	4.116

CI : confidence interval, GAV : gravity-assisted valve

gress has been made in shunt technology, the rate of shunt-related complications remains high. Of such complications, overdrainage appears to be the most frequent problem requiring resolution.

Reports of overdrainage rates in the literature differ widely, ranging from 3% to 70%^{3,7,8}, but 20% seems to be the rate cited most often^{5,27}. Recently, new shunt technologies have been introduced to minimize overdrainage, including the GAV (the concept for which had already been introduced by Hakim in 1975), the programmable valve, and the programmable GAV^{9,17,23}.

Shunt failures and complications

In our series, 19 revisions were performed in 15 patients. The most common cause for shunt revision was underdrainage in 13 patients ($p = 0.167$), followed by proximal obstruction in 3 patients, infection in 2 patients, and overdrainage in 1 patient (Fig. 1). The overall shunt failure rate was 16.2%. Complications not requiring revision were found in 22 patients : overdrainage in 20 patients, infection in 1 patient, and valve exposure in 1 patient. Infection was found in 4 patients : valve exposure in 2 patients and CSF infection in 2 patients. The overall infection rate was 3.6%, which was

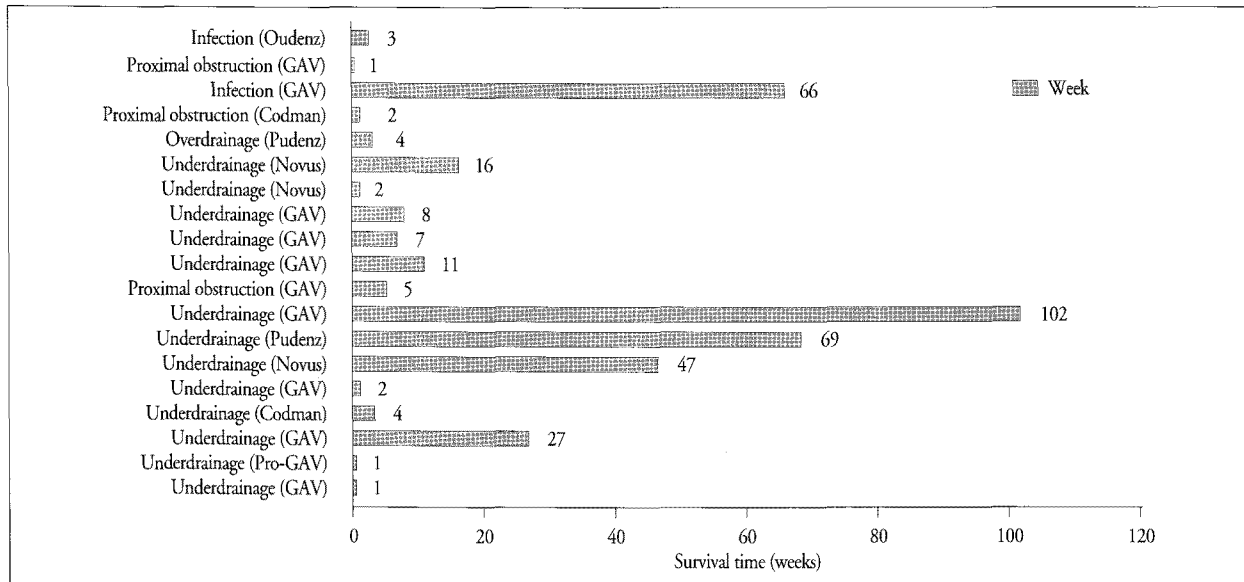


Fig. 2. Lifetime of valves since implantation and reasons for revision in 15 patients (19 valves).

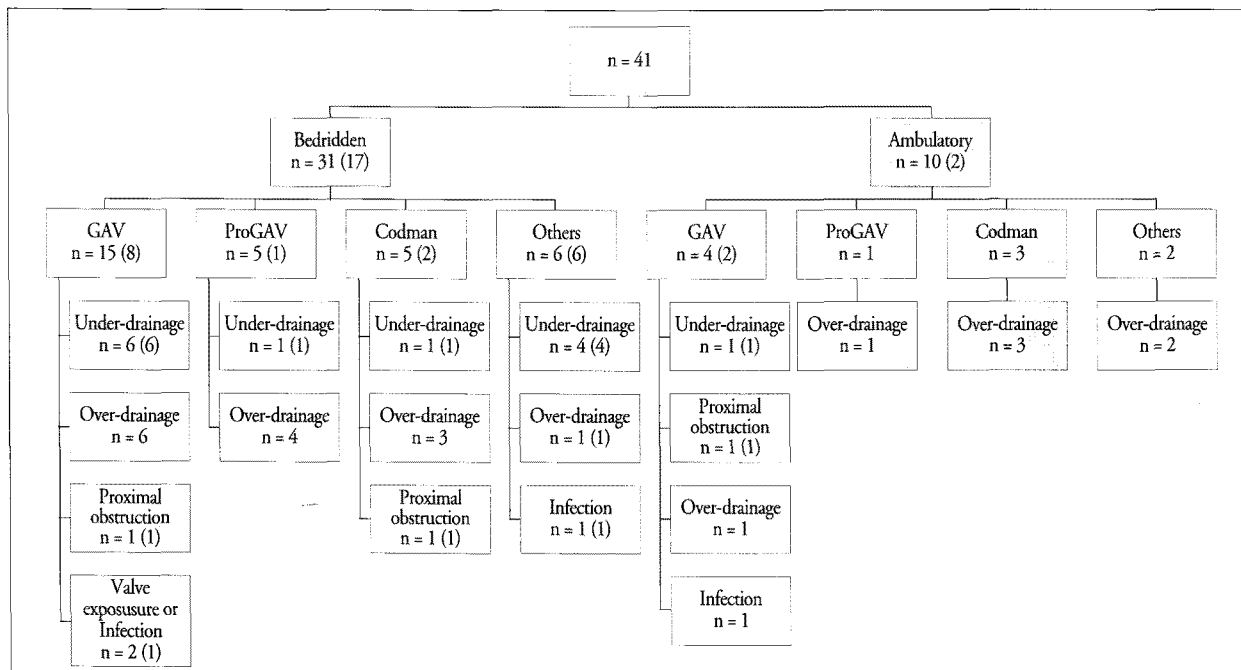


Fig. 3. Developments of complications according to patient mobility and the type of valve; n = number of complications (number of revisions).

strikingly low compared with previous research. The 1-year survival rate was 81%, and the overall shunt failure was 16.2%; these findings are in agreement with other recent reports^{12,13,23,24}. Seven patients who demonstrated overdrainage had cranial defects when shunt surgery was performed (41%, $p = 0.629$). Two patients required surgical drainage for chronic subdural hematoma (SDH). Five patients who had overdrainage (3 GAVs and 2 ProGAVs) improved after cranioplasty ($p = 0.093$).

Efficacy of GAVs

GAV was developed as an alternative device to prevent overdrainage. GAV design consists of 2 valves in 1 housing: one is a posture-independent, helix-spring, ball-cone valve (low-pressure valve), and the other is a posture-sensitive valve (gravitational unit). In the horizontal position, the gravitational unit is deactivated. As soon as the patient moves from the prone position, the Tantalum ball loads the ball-cone valve in a posture-dependent fashion, and CSF flow is obstructed¹⁴. Based on this design, one might suppose that the rate of overdrainage in bedridden patients would be higher than in ambulatory patients. However, this assumption was not evident in our results. Since the frequency of cases (13.4%) with overdrainage using GAV was lower than the frequency using any other shunt (23.7%), our findings validated that GAV was effective in avoiding overdrainage. However, the complication rate of underdrainage was 13.5%, which was slightly higher than that for any other shunt (10.1%). Furthermore, more frequent revisions were required with GAV for the complication of underdrainage than for any other shunt.

Shunt performance can be defined by the following equation: intraventricular pressure = valve opening pressure + intraperitoneal pressure - hydrostatic pressure. When a patient is in a supine position, hydrostatic pressure is decreased. In the supine position, anterior inclination of the gravitational valve by more 20° relative to the vertical leads to a disproportionately high opening pressure compared with an inclination of less than 20° between the head and abdomen^{11,19}. Thus, in order to ensure optimal performance, the valve must be implanted correctly along the body axis. However, bedridden patients may experience underdrainage even though correct implantation of valve is achieved (although bedridden patients, in theory, should experience overdrainage). Anterior inclination of the valve can be achieved by elevation of the head with use of pillows, and in both nursing homes and home patient care, bedridden patients are frequently positioned in this way^{6,11}. Furthermore, they spend less time in an upright position, which may lead to a lack of hydrostatic pressure⁹. This may explain why many bedridden patients receiving GAV shunts experience underdrainage.

In our study, 7 patients with GAV were revised for underdrainage (6 bedridden and 1 ambulatory). They showed valve inclinations of 9°, -24.5°, 13°, 17°, 2°, 10°, and 16°. Two patients showing inclinations of 28° and 25° were revised in another hospital because of underdrainage. In bedridden patients, underdrainage requiring revision was higher, but severe anterior inclination was not found. These results reveal that the head inclination in bedridden patients might explain underdrainage rather than severe anteriorly inclined implantation of GAV in this study.

Efficacy of programmable valves

The GAV was introduced to avoid overdrainage, and the programmable valve was introduced to reduce overdrainage-related complications. The programmable valve provides noninvasive pressure adjustment, eventually reducing the rate of shunt revisions. Numerous neurological surgeons have emphasized that programmable valves improve outcome and shunt survival rate^{12,20,22,25,29-31}. However, many neurological surgeons tend to overlook neurological changes, focusing on radiological changes. They largely describe radiological improvement and only infrequently discuss neurological improvement^{1,25,31}.

We performed pressure adjustments in 11 overdrainage patients. The number of adjustments ranged from 3 to 10 (mean, 7), and the interval between adjustments ranged from 3 days to 2 weeks (mean, 6.5 days). Only 3 patients were improved both radiologically and neurologically after adjustment. Only 1 of 5 patients with ProGAV and 2 of 6 patients with CHPV improved after adjustment ($p = 0.146$). One patient with ProGAV showed a preoperative HHS of 11 and a postoperative HHS of 8, a nonsignificant difference. Overdrainage was improved radiologically after 2 adjustments. One of the 2 CHPV patients had a preoperative HHS score of 17 and a postoperative HHS score of 9; he also experienced overdrainage. Radiological overdrainage was improved and neurological status was preserved following 3 adjustments. The other patient also showed a preoperative HHS of 17 but a postoperative HHS of 13. After 2 adjustments and a cranioplasty, radiological overdrainage was improved and neurological status was preserved. However, all other patients continued to suffer persistent overdrainage or neurological deterioration. Although neurological improvement was obtained just after VP shunting, readjustment of the valve to correct overdrainage-while leading to radiological improvement-also produced neurological deterioration.

Based on imaging studies, programmable valves can reduce either overdrainage or underdrainage through pressure readjustment, lowering revision rates and leading to cost benefits for both hospitals and patients³¹. In our series, the rate of

overdrainage was similar to that reported in other articles, but the revision rate was lower compared with other research on similar patient populations and valves^{13,25}. This suggests that programmable valves may reduce the rate of revision and improve survival times. However, even though programmable valves may prolong mechanical survival, if neurological deterioration follows adjustment, they may represent only a superficial solution to the problem. We must not overlook neurological deterioration after pressure adjustment.

Cranial defects

The frequency of overdrainage complications was 41% in patients with cranial defects ($p = 0.629$), and overdrainage spontaneously regressed in 71% of these patients after cranioplasty ($p = 0.093$). It was thought that atmospheric pressure (760 mmHg) have overcome the valve opening pressure after shunt surgery. We therefore perform cranioplasty prior to shunt surgery as a means of reducing overdrainage.

CONCLUSION

Despite technical advances in the treatment of hydrocephalus, completely successful shunt surgery is still a formidable task. If a candidate for VP shunt is bedridden, use of a GAV is not indicated because it may lead to underdrainage. Careful procedure and perioperative management can reduce infection rate. The programmable valve is a distinctly beneficial system but may be overvalued as a solution in some respects; when using a programmable valve, it is imperative not to overlook neurological deterioration after pressure adjustment even in the presence of radiological improvement. It may be beneficial to perform cranioplasty prior to VP shunting. One limitation of the present study is the small sample size, which might have been insufficient to achieve statistical significance. Thus, further studies on different large populations are needed.

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