Use of External Lumbar Cerebrospinal Fluid Drainage and Lumboperitoneal Shunts with Strata NSC Valves in Idiopathic Normal Pressure Hydrocephalus: A Single-Center Experience

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Key words
- Cerebrospinal fluid
- Dementia
- Idiopathic normal pressure hydrocephalus

Abbreviations and Acronyms

CSF: Cerebrospinal fluid
DESH: Disproportionately enlarged subarachnoid-space hydrocephalus
ELD: External lumbar drainage
FAB: Frontal Assessment Battery
iNPH: Idiopathic normal-pressure hydrocephalus
JNPHGS: Japan Normal-Pressure Hydrocephalus Grading Scale
LP: Lumboperitoneal
MMSE: Mini-Mental State Examination
mRS: Modified Rankin Scale
SINPHONI: Study of iNPH on Neurological Improvement
TUG: 3-minute up-and-go test
VP: Ventriculoperitoneal

OBJECTIVE: In Japan, idiopathic normal pressure hydrocephalus (iNPH) currently is treated mainly with lumboperitoneal (LP) shunts. Our aim was to evaluate whether LP shunting via the use of Medtronic Strata NSC programmable valves was as effective as ventriculoperitoneal shunting in the treatment of patients with iNPH from the perspectives of safety and symptomatic improvement rate.

METHODS: The clinical records of 51 iNPH patients (mean age, 75 years; males, 29), who underwent placement of Medtronic Strata NSC LP shunt systems were reviewed retrospectively as a cohort. LP shunting was evaluated with the modified Rankin Scale, the Japan Normal-Pressure Hydrocephalus Grading Scale, the Mini-Mental State Examination, the Frontal Assessment Battery, and the Trail-Making Test A as outcome measures.

RESULTS: Modified Rankin Scale scores improved from 3.2 to 2.2 \((P < 0.01)\), indicating a 64% response rate 12 months after treatment. Total Japan Normal-Pressure Hydrocephalus Grading Scale scores decreased from 6.5 to 4.0 \((P < 0.01)\), indicating a response rate of 81%. Mini-Mental State Examination scores improved from 22.2 to 25.4 \((P < 0.01)\), Frontal Assessment Battery scores improved from 11.7 to 13.4 \((P < 0.05)\), and Trail-Making Test A scores improved from 122.3 to 112.7 \((P = 0.60)\). During the 12-month follow-up period, complications requiring surgery were observed in 6 cases \((11.8\%)\).

CONCLUSION: LP shunts showed effectiveness rates that were similar to those of ventriculoperitoneal shunts. Despite the relatively high complication rate, LP shunts can be recommended for the treatment of patients with iNPH because of their minimal invasiveness and lack of lethal complications.

INTRODUCTION

Idiopathic normal-pressure hydrocephalus (iNPH) \((1)\), a condition of uncertain etiology that characteristically afflicts elderly patients, is treated by cerebrospinal fluid (CSF) shunting. iNPH is characterized by the classical triad of symptoms: gait disturbance, dementia, and urinary incontinence. Recent reports of prevalence rates of 0.51% and 1.4% in community-dwelling elderly people have suggested that iNPH is more common than previously thought \((9, 18)\). The accurate diagnosis and treatment of this disease are expected to reduce the burden on patients’ families and society as a whole \((3)\).

Because of the current emphasis on minimally invasive treatments, in Japan iNPH is treated mainly with lumboperitoneal (LP) shunts \((2)\) (Table 1); however, in Western countries, ventriculoperitoneal (VP) shunts are used to treat iNPH in most cases partially because there is currently no established evidence for the use of LP shunts as a treatment for iNPH \((3)\). Regarding the shunt device, many shunt systems are designed for VP shunting; therefore, surgeons adapt systems for LP shunting according to their actual needs. In this situation, we have chosen the LP shunt kit 44421 (Medtronic, Inc., Goleta, California, USA), which includes a small-lumen peritoneal catheter and a Strata NSC LP programmable valve, the only LP shunt programmable valve approved by the Food and Drug Administration in the United States. Because there are no reports on the use of this device in patients with iNPH, we would like to provide the present report as an important base for establishing LP shunts as a treatment for this condition.

The purpose of this study was to examine the improvement rates of symptoms in patients who were suspected of having iNPH or so-called “possible iNPH” \((15)\) based on their neurologic manifestations and the results of tests and imaging 12 months after treatment with Strata NSC LP programmable shunts. We compared the outcome of
patients treated with LP shunts with the outcome of patients previously treated with VP shunts in other published series. Our aim was to verify whether LP shunts when used with our approach to treatment are as effective as VP shunts in the management of patients with iNPH regarding safety and symptomatic improvement rate.

METHODS

The subjects of this study (N = 51) were reviewed retrospectively as a cohort of patients who received LP shunts, after consulting our department. They were suspected of having iNPH based on their neurologic manifestations and findings on magnetic resonance imaging (MRI) scans. Tap tests evaluation criteria was consistent with Japanese guidelines for iNPH(15). The result was deemed positive if, within 1 week after removal of CSF, any of the following were found: 1) improvement of any item on the “Japanese normal pressure hydrocephalus grading scale revised” (JNPHGS) (16); 2) ≥10% improvement on the 3-minute up-and-go test (TUG); or 3) ≥3-point improvement on the Mini-Mental State Examination (MMSE) (6). The JNPHGS is a clinician-rated scale that is used to rate separately the severity of each of the triad symptoms of iNPH gait (disturbance, cognition, and urination). The score on each domain ranges from 0 to 4. Grade 0 is normal, and grade 1 indicates subjective symptoms with an absence of objective disturbances. Grades 2, 3, and 4 indicate mild, moderate, and severe disturbances, respectively. The evaluation was performed by a single, third-party neuropsychologist. Forty-six patients were selected on the basis of their positive TTs, and another 5 patients with negative TTs were selected after an additional external lumbar drainage (ELD), as described in the section “Drainage Test.” All 51 patients diagnosed with iNPH were considered indicated for shunting and had LP shunts inserted. We used the same type of shunt components for LP shunting in all patients.

The spinal catheter was a commonly used one, with 0.7 mm internal diameter and 1.5 mm outer diameter, whereas the small-lumen peritoneal catheter had the same 0.7-mm internal diameter as the spinal catheter and a 2.5-mm outer diameter. All were components of the Medtronic Strata NSC LP shunt system. The lengths of the small lumen peritoneal catheters could influence the overall outflow resistance of the shunt system. The valves had the full range of performance levels: 0.5 (15–35 mmHg), 1.0 (35–55 mmHg), 1.5 (50–110 mmHg), 2.0 (145–165 mmHg), and 2.5 (200–220 mmHg). Therefore, we used 30-cm long

**Table 1. Treatment of Idiopathic Normal-Pressure Hydrocephalus in Japan According to the Questionnaire Surveys**

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of facilities</th>
<th>iNPH patients</th>
<th>VP shunts</th>
<th>LP shunts</th>
<th>VA shunts</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>251</td>
<td>1211</td>
<td>855</td>
<td>324</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>2011</td>
<td>289</td>
<td>1608</td>
<td>761</td>
<td>846</td>
<td>15</td>
<td>14</td>
</tr>
</tbody>
</table>

Arai et al., 2009 [2]. Neurosurgery centers: 1108; Recovery rate: 39% (289 centers). The number of cases that were treated increased by approximately 400 from those reported in the survey performed 4 years earlier; the total number of cases of treated iNPH was 1608. Notably, more cases were treated with LP shunts than with VP shunts. Currently, iNPH is mainly treated with LP shunts in Japan. The category of interest is the boldface figures.

iNPH, idiopathic normal pressure hydrocephalus; VP, ventriculoperitoneal; LP, lumboperitoneal; VA, ventriculoatrial.

Figure 1. Comparison of images acquired before and after lumbaroperitoneal (LP) shunting; the shunting pressure was reduced stepwise over the course of approximately 3 months to the postoperative benchmark, at which diagnostic imaging showed cancellation of the compression in high convexity. Top: comparison of high convexity (computed tomography) before and after the LP shunting; the sulcus in high convexity is unclear before the operation, whereas it is depicted after the operation. Bottom: callosal angle in magnetic resonance imaging (T1-weight image, coronal section); the angle between the white lines is acute (<90°) before the LP shunting, whereas it becomes an obtuse angle (>90°) after the operation.
peritoneal catheters in all patients, which were shortened from the original 120 cm length provided by the manufacturer.

**LP Shunting and Management**
The clinical records of iNPH patients who underwent placement of Medtronic Strata NSC LP shunt systems between July 2010 and April 2012 were reviewed retrospectively. iNPH was clinically diagnosed in these patients according to the classical triad of gait impairment, urinary incontinence, and impaired mental function, and supported by ventricular dilation, dilation of Sylvian fissures and narrowing of sulci and subarachnoid spaces over the high convexity without significant cerebral atrophy as seen on computed tomography or MRI. The evaluation criteria were consistent with Japanese guidelines for iNPH (15).

To date, 51 cases have been followed-up for 12 months or longer. The average age was 75.0 ± 6.4 years (mean ± standard deviation), and the male-to-female ratio was 29:22, with male patients being slightly more prevalent. MRJ showed the presence of the so-called disproportionally enlarged subarachnoid-space hydrocephalus (DESH) (7, 12) type in 80% of the patients, with the remaining 20% having other types. The deep white matter lesions observed were mild in approximately 60% of the patients, and moderate to severe in about 40% of the cohort.

The valves were adjusted before implantation to an initial performance level of 2.5 for all patients. The reason for the use of the greatest setting was that we aimed to reduce the rate of overdrainage symptoms (e.g., low-pressure headache and subdural hematoma), caused by CSF leakage from the penetration of the dura into the epidural space immediately after surgery (12). The proper pressure setting of the LP shunt was determined around 1 month after the operation by reference not only to the remaining neurological symptoms related to iNPH but also to neuroimaging (post-shunting computed tomography and MRJ criteria (depiction of sulci in the high convexity and change of the callosal angle to obtuse) (10) in diagnostic head images (Figure 1). At 1, 3, 6, 9, and 12 months after surgery, the patients attended an outpatient follow-up consultation, during which a puncture of the shunt valve reservoir was conducted using a 27-gauge needle and CSF was aspirated using negative pressure, to check for the smooth outflow of CSF and the presence or absence of shunt occlusion.

The LP shunting was evaluated 12 months after surgery using the modified Rankin Scale (mRS), INPHGS, MMSE, the Frontal Assessment Battery (FAB) (5), the Trail-Making Test A (17), and the Wechsler Adult Intelligence Scale III symbol search (5) as outcome measures.

**Drainage Test**
Five elderly people (2 men and 3 women; age range, 72–83 years; average age, 77.4 years) were categorized as having possible iNPH on the basis of their clinical symptoms and MRI findings despite their TTs being negative. The patients were subjected to a 5-day drainage test, which was performed as follows: while the patient was under local anesthesia, a 14-gauge Tuohy needle was introduced into the lumbar subarachnoid space at the L2–L3 or L3–L4 intervertebral space. Next, a spinal catheter was inserted through the Tuohy needle into the lumbar subarachnoid space and directed 20 cm cephalad. Before and after ELD, all patients were evaluated using the INPHGS, the MMSE, and the TUG. The response to the ELD was predefined by the 3 following major scales: INPHGS, TUG, and MMSE. Improvements consisting of 1 point or more on the iNPH grading scale (total), a greater than 10% improvement in time on the TUG, or more than 3 points on the MMSE were regarded as a positive result.

**Surgical Technique of LP Shunting (Video 1)**
Lumbar spinal anesthesia combined with local anesthesia was standard. A right lateral position was used after confirming the anesthetized level in the supine position. The paramedian approach usually was chosen for lumbar punctures to avoid catheter troubles because, in elderly patients, the interlaminar space might be narrow. For paramedian punctures, the Tuohy needle was inserted pointing at an angle of 45 degrees cranially, and the lumbar catheter
was inserted to the rostral side with forceps until its presence was confirmed into the lumbar subarachnoid space. The catheter was then advanced for about 10–15 cm into the lumbar subarachnoid space. The following 3 incisions were made: a 2-cm lumbar incision, a 2-cm linear abdominal incision, and a 4- to 5-cm lateral transverse abdominal incision. A subcutaneous tunnel was made between the relay point and the peritoneal side using a disposable passer. The peritoneal catheter was cut so that about 30 cm of the catheter would be inserted into the abdominal cavity. For the abdominal side, operations were performed in the lateral position, and the abdominal skin incision was made on the left side. Insertion of the shunt valve was achieved from the abdominal side or the back side. However, the shunt valve was fixed to the fascia or under the skin at 2 points close to each other to prevent moving or flipping.

With a 20-cm lumbar catheter placed into the thecal sac, the tube was tunneled subcutaneously into the abdominal incision, where it was secured to the proximal end of the valve. The abdominal wall layers were dissected, exposing and opening the peritoneum. A subcutaneous pouch for the valve was prepared at the abdominal-side incision. The enlarged end of the peritoneal catheter was connected to the distal end of the valve. After confirmation of free distal CSF flow, the distal end was introduced intraperitoneally. Fixation tabs were used to fix the proximal and distal catheters to the surrounding fascia.

**Statistical Analyses**

The cognitive examinations performed before and after the placement of the LP shunts were compared. All statistical analyses were performed using SPSS Version 18.0 (SPSS for Windows, IBM, Armonk, New York, USA). Nonparametric statistical methods were used in all analyses. The Wilcoxon signed ranks test was used for within-group comparisons before and after LP shunting. Continuous variables, such as patient demographics before and after LP shunting, were compared using Student's t test. Significance was defined as $P < 0.05$. All subjects provided informed consent to participate in the research protocol that was approved by the Ethics Committee of Juntendo University.
RESULTS

LP Shunting
Most patients experienced symptomatic improvement 12 months after the LP shunt surgery according to the JNPHGS, which in average indicated that gait disturbances were decreased from $2.5 \pm 0.76$ to $1.7 \pm 0.95$ ($P < 0.01$), dementia was decreased from $2.1 \pm 1.1$ to $1.2 \pm 1.14$ ($P < 0.01$), and urinary disturbances were decreased from $2.0 \pm 0.11$ to $1.2 \pm 1.0$ ($P < 0.01$). The total score on the JNPHGS decreased from $6.5 \pm 2.41$ to $4.0 \pm 2.43$ ($P < 0.01$), indicating an 81% response rate. A response rate greater

Figure 3. Changes in the results of the Mini-Mental Scale Examination (MMSE; total score is 30, and individuals are judged as normal if the score is >24), Frontal Assessment Battery (FAB; total score is 18), and Trail-Making Test A (TMT-A) 12 months after the shunting compared with those recorded before the shunting. **$P < 0.01$, Student’s $t$ test.

Figure 4. Case of proximal catheter occlusion: because outflow of cerebrospinal fluid was not obtained even after the paracentesis of the valve using a 27-gauge needle, shuntogram was used using a contrast medium (A). The contrast medium managed to flow into the shunt valve, despite reflux to the lumbar side. However, the medium remained pooled without diffusion, moved up and down, and was pooled when the subject changed posture (B and C). The top of the spinal catheter appeared to have strayed into the epiarachnoid space, requiring shunt revision.
than 90% was observed in DESH-type patients. In addition, mRS scores exhibited a statistically significant improvement, from 3.2 ± 0.69 to 2.2 ± 0.99 (P < 0.01), which indicated a 64% response rate 12 months after treatment (Figure 2).

The testing of higher brain functions at 12 months after treatment revealed that MMSE scores improved from 22.2 ± 3.54 (24.9 ± 4.62) postoperatively (P < 0.01), FAB scores improved from 11.7 ± 3.54 (11.3 ± 3.51) to 13.4 ± 2.77 (13.5 ± 3.18) (P < 0.05), Trail-Making Test A scores improved from 122.3 ± 89.74 (125.2 ± 81.3) to 112.7 ± 81.09 (110.2 ± 71.35) (P = 0.61), and Wechsler Adult Intelligence Scale III symbol searches improved from 11.64 ± 8.49 to 15.7 ± 9.29 (P = 0.06) (Table 2). The comparison of preoperative and postoperative cognitive functions revealed a statistically significant increase in the MMSE and FAB scores (Figure 3).

In addition, during the 12-month follow-up period, complications requiring surgery were observed in 6 cases (11.8%): shunt infection was observed in 1 case (2.0%), subdural hematoma was observed in 1 case, spinal (proximal) catheter occlusions were observed in 2 cases (3.9%) (Figure 4), procedure-related radiculopathy was observed in 1 case, and prolapse of the peritoneal (distal) catheter was observed in 1 case. Overdrainage was observed in 7 cases (13.7%). All of these complications were improved by adjustment of the valve performance level, with the exception of 1 case (2.0%), with a subdural hematoma requiring evacuation.

DISCUSSION

LP shunts are seldom used for iNPH treatment in Europe and North America. Among the various conceivable reasons for this low usage, the high complication rate that has been reported for LP shunts is the most important. Toma et al. (19) performed LP shunts in 20 patients aged 40.3 years on average using a Strata NSC programmable valve and reported that 7 of their patients (35%) required shunt revision. The majority of these reports were on patients with idiopathic intracranial hypertension and slit-ventricle syndrome who were young and active in their daily life. We believe that high CSF pressure and trunk motion could be the cause for displacement of the proximal/distal shunt catheters. However, although there is a low number of reports on the use of LP shunts for the treatment of iNPH, Bloch and McDermott performed LP shunts in 33 patients with iNPH using the Integra H/V valve systems (Integra LifeSciences Corporation), resulting in 9 patients (27%) requiring re-operation during the follow-up period, which averaged 19 months (4). Although the follow-up period of our cases was short, the rate of complications requiring shunt revision was 6 of 51 cases (11.8%). We cannot simply compare our results with those listed previously because elderly iNPH patients with LP shunts are characterized by poor activity and lower CSF pressure, which are probably related to fewer complications.

In contrast, studies of iNPH treatment with VP shunts include a multicenter study that used a programmable valve (11) in all patients diagnosed with possible iNPH based on their neurologic manifestations and imaging studies. An evaluation using a JNPH grading scale and mRS (for the assessment of daily activities) performed 1 year after treatment revealed that approximately 80% and 60% of improvement was seen, respectively (Table 3). In addition, according to Klinge et al. (14), who published an European multicenter study in 2012, symptomatic improvement in iNPH was observed, with 69% and 84% response rates on the mRS and iNPH scales, respectively; whereas 17 of 115 subjects (15%) required shunt revision during a 1-year period (Table 3) (8). The rates of intracranial bleeding requiring surgery and infection were both 1%. Within the first year after surgery, approximately 80% of cases showed an improvement of 1 point or greater on the JNPHGS, which was similar to the findings of the Study of iNPH on Neurological Improvement (SINPHONI). An evaluation performed using the mRS showed improvement of 1 grade or more in

**Table 3. Response and Complications: Comparison of the Results Between VP Shunting (European Study Performed in 2012 and SINPHONI) and LP Shunting (Ours), Operated 1 Year After**

<table>
<thead>
<tr>
<th></th>
<th>VP Shunting (Klinge et al. (14), European study n = 115)</th>
<th>VP Shunting (Hashimoto et al. (7), SINPHONI n = 100)</th>
<th>LP Shunting (this study Nakajima et al.; n = 51)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Response rate</strong></td>
<td>mRS</td>
<td>mRS</td>
<td>mRS</td>
</tr>
<tr>
<td></td>
<td>69%</td>
<td>69%</td>
<td>64%</td>
</tr>
<tr>
<td></td>
<td>mRS</td>
<td>84%</td>
<td>80%</td>
</tr>
<tr>
<td><strong>Complication rate</strong></td>
<td>Complications requiring shunt surgery (total)</td>
<td>Complications requiring shunt surgery (total)</td>
<td>Complications requiring shunt surgery (total)</td>
</tr>
<tr>
<td></td>
<td>15%</td>
<td>1%</td>
<td>11.8%</td>
</tr>
<tr>
<td></td>
<td>Complications not requiring shunt surgery (total)</td>
<td>Complications not requiring shunt surgery (total)</td>
<td>Complications not requiring shunt surgery (total)</td>
</tr>
<tr>
<td></td>
<td>13%</td>
<td>13%</td>
<td>11.8%</td>
</tr>
<tr>
<td></td>
<td>Hematoma and hygroma requiring evacuation</td>
<td>Hematoma and hygroma requiring evacuation</td>
<td>2.0%</td>
</tr>
<tr>
<td>Hematoma</td>
<td>1%</td>
<td>1%</td>
<td></td>
</tr>
<tr>
<td>Hygroma</td>
<td>6%</td>
<td>6%</td>
<td>2.0%</td>
</tr>
<tr>
<td>Infection (fever +</td>
<td>1%</td>
<td>N/A</td>
<td>2.0%</td>
</tr>
<tr>
<td>cell count)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Valve failure</td>
<td>4%</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Proximal catheter</td>
<td>4%</td>
<td>1%</td>
<td>3.9%</td>
</tr>
<tr>
<td>Distal catheter</td>
<td>4%</td>
<td>N/A</td>
<td>2.0%</td>
</tr>
<tr>
<td>failure</td>
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</tbody>
</table>
| SINPHONI: The Study of iNPH on Neurological Improvement; mRS, modified Rankin Scale; NPHGS, Normal-Pressure Hydrocephalus Grading Scale; N/A, not available.

![Figure 2](http://dx.doi.org/10.1016/j.wneu.2014.08.004)
64% of the cases, which was a little lower than the 69% observed in the European Study and in SINPHONI. We considered that VP shunts tend to have lower rates of revision caused by occlusion, displacement, and other complications related to the shunt catheter compared with those of LP shunts.

However, although VP shunts are not associated with such greater rates of device-related complications, they tend to be a more invasive surgery (requiring general anesthesia and brain intervention) and yield complications with a greater impact on the general condition of the patient. Patients with iNPH are elderly, with relatively higher rates of amyloid angiopathy and AD comorbidity. An increased risk of intracranial hemorrhage has been associated with VP shunt placement. MRI T2\* can be used to assess coexisting amyloid angiopathy (20) and eventually avoid shunt treatment based on the anticipated risks. In contrast, there are also specific complications of the LP shunt, the aberrant spinal catheter (Figure 4) and the procedure-related radiculopathy, which usually improves with removing the catheter under local anesthesia. As an elderly population, patients with iNPH tend to have a relatively high incidence of lumbar stenosis. The optimal evaluation to avoid complications requires a “whole-spine” MRI examination to confirm adequacy of the lumbar subarachnoid space and its continuity with the rest of the CSF spaces.

CONCLUSION

Although our data are based on a retrospective survey at a single center, LP shunts showed effectiveness rates similar to those of VP shunts. Despite the high complication rate inherent to this procedure, LP shunting can be recommended for the treatment of patients with iNPH because of their minimal invasiveness and lack of the lethal complications seen with VP shunts. A multi-institutional trial would definitely be of need.

REFERENCES