The development of hydrocephalus after aneurysmal subarachnoid hemorrhage (SAH) is a significant complication among patients. The introduction of the first ventriculoperitoneal (VP) shunt in 1952 helped to transform the management of hydrocephalus. This was further revolutionized with the introduction of programmable VP shunts in the 1980s. With programmable shunts, overdrainage and underdrainage of CSF could be treated with noninvasive adjustments to the pressure settings, either by increasing or decreasing the valve settings, respectively. Because the settings can be adjusted noninvasively, the number of operations done for revision of nonprogrammable shunts for drainage-associated complications could be reduced.

Object. The choice of programmable or nonprogrammable shunts for the management of hydrocephalus after aneurysmal SAH remains undefined. Variable intracranial pressures make optimal management difficult. Programmable shunts have been shown to reduce problems with drainage, but at 3 times the cost of nonprogrammable shunts.

Methods. All patients who underwent insertion of a ventriculoperitoneal shunt for hydrocephalus after aneurysmal SAH between 2006 and 2012 were included. Patients were divided into those in whom nonprogrammable shunts and those in whom programmable shunts were inserted. The rates of shunt revisions, the reasons for adjustments of shunt settings in patients with programmable devices, and the effectiveness of the adjustments were analyzed. A cost-benefit analysis was also conducted to determine if the overall cost for programmable shunts was more than for nonprogrammable shunts.

Results. Ninety-four patients underwent insertion of shunts for hydrocephalus secondary to SAH. In 37 of these patients, nonprogrammable shunts were inserted, whereas in 57 programmable shunts were inserted. Four (7%) of 57 patients with programmable devices underwent shunt revision, whereas 8 (21.6%) of 37 patients with nonprogrammable shunts underwent shunt revision (p = 0.0413), and 4 of these patients had programmable shunts inserted during shunt revision. In 33 of 57 patients with programmable shunts, adjustments were made. The adjustments were for a trial of functional improvement (n = 21), overdrainage (n = 5), underdrainage (n = 6), or overly sunken skull defect (n = 1). Of these 33 patients, 24 showed neurological improvements (p = 0.012). Cost-benefit analysis showed $646.60 savings (US dollars) per patient if programmable shunts were used, because the cost of shunt revision is a lot higher than the cost of the shunt.

Conclusions. The rate of shunt revision is lower in patients with programmable devices, and these are therefore more cost-effective. In addition, the shunt adjustments made for patients with programmable devices also resulted in better neurological outcomes.

(ARTICLE LINK)

Key Words • shunt • hydrocephalus • subarachnoid hemorrhage • cost analysis • vascular disorders

Abbreviations used in this paper: ICP = intracranial pressure; NPH = normal-pressure hydrocephalus; SAH = subarachnoid hemorrhage; SDH = subdural hemorrhage; VP = ventriculoperitoneal.
problems has decreased.\textsuperscript{4,15,23} However, the cost of a programmable shunt is almost 3 times that of a nonprogrammable shunt in our country.

Much of the published literature on programmable versus nonprogrammable shunts is based on pediatric congenital hydrocephalus and normal-pressure hydrocephalus (NPH). The aim of our study was to analyze our institution’s data and determine if the use of a programmable or a nonprogrammable shunt is more suitable for the management of hydrocephalus after aneurysmal SAH in patients who often have a secondary form of NPH. We sought to determine if programmable or nonprogrammable shunts had lower revision rates and if the adjustments made to the shunt settings in the programmable shunts resulted in better clinical outcomes in our patients. We also carried out a cost-benefit analysis to determine if the use of programmable shunts was more expensive overall than the use of nonprogrammable shunts for the estimated length of hospital stay in this group of patients.

Methods

We conducted an internal review board–approved retrospective analysis of all the patients in our shunt registry in whom a shunt was inserted for the management of hydrocephalus after aneurysmal SAH between 2006 and 2012. The patients were divided into 2 groups depending on whether they had received nonprogrammable CSF flow-diverting VP shunts or programmable Strata shunts (both from Medtronic, Inc.). The choice of whether to insert programmable or nonprogrammable valves was entirely dependent on the surgeon’s preference. There were no differences in patients’ symptoms or presentations.

For impartiality and so that there was no conflict of commercial interest, we included programmable and nonprogrammable shunts from only one company (Medtronic, Inc.). Hence, patients with postaneurysmal SAH who had received other types of programmable valves such as proGAV or Hakim-Codman valves were excluded from our study. We went through our electronic databases, inpatient case notes, intraoperative notes, relevant imaging, and discharge summaries of individual patients to look for events that occurred during the inpatient stay. Outpatient clinical notes were also obtained to calculate the length of follow-up for these patients, to look at the number of shunt adjustments made in the outpatient clinics, and to see if any long-term complications developed. The CT brain scans obtained for postinsertion shunt setting adjustments were also reviewed to determine if there were any changes to ventricular sizes.

We compared the rate of shunt revision in both groups and the incidence of overdrainage and underdrainage. The CT scans as well as inpatient notes before and after shunt revision were reviewed. Patients whose postoperative CT scan demonstrated persistently large ventricles and an Evans ratio of > 0.3 and who were still symptomatic (that is, had drowsiness, gait difficulties, memory deficits, and/or headaches) were regarded as having shunt underdrainage. Patients whose postoperative CT scan demonstrated evidence of subdural hemorrhages (SDHs) were regarded as having shunt overdrainage. In the group with programmable shunts, the reason for each change in shunt setting was recorded and analyzed. The time that each of the adjustments was made was also recorded. We also sought to analyze if adjustments made to the settings in the programmable valves resulted in improved neurological outcomes.

The patients’ pre- and postadjustment Glasgow Coma Scale scores as well as symptoms such as headaches and levels of alertness were recorded in the inpatient notes by doctors and nurses caring for the patient, and in the outpatient notes by doctors assessing the patient in the clinic. The individual patient’s memory function was evaluated by the occupational therapists and gait was assessed by the physiotherapists and doctors. Improvements in neurological outcomes were defined as increase in postadjustment Glasgow Coma Scale score, increase in alertness, resolution of headaches, and improvement in memory and gait. The long-term outcomes of patients in both groups who received shunts for hydrocephalus secondary to SAH were also reviewed and compared.

Statistical analysis was performed with SPSS. The Fisher exact test was performed on categorical data. The level of significance was \( p < 0.05 \). Kaplan-Meier curves were drawn with MedCalc version 12.3.0.

A cost-benefit analysis was also conducted to determine if the use of programmable shunts was more expensive than nonprogrammable shunts in the treatment of hydrocephalus post-SAH. The calculations were based on the cost of shunts, average length of hospital stay, CT scans, and outpatient follow-up in the year 2012. The costs quoted in our study are based on US dollars (US$).

Results

Our shunt registry showed a total of 178 patients who underwent the insertion of VP shunts between 2006 and 2012 for a wide range of different pathologies such as NPH, posttraumatic hydrocephalus, obstructive hydrocephalus secondary to tumors, hydrocephalus secondary to hemorrhagic stroke, and hydrocephalus after aneurysmal SAH. After excluding patients with proGAV or Hakim-Codman shunts, we found that 94 patients had received either nonprogrammable CSF flow-diverting VP shunts or programmable Strata valve shunts (both from Medtronic, Inc.) for hydrocephalus occurring after aneurysmal SAH. The patients were between 32 and 79 years (mean 58.54 ± 11.45 years) of age, and the duration of their follow-up was between 1 and 73 months (mean 26.32 ± 18.73 months); the means are expressed ± SD. In 37 of these patients nonprogrammable CSF flow-diverting VP shunts were inserted; 4 of these patients subsequently had their shunts revised and changed to programmable Strata valve devices. In 57 patients programmable Strata valve shunts were inserted. The types of shunts inserted (programmable or nonprogrammable) were entirely dependent on the surgeon’s preference.

There were 8 (21.6%) shunt revisions in the patients with nonprogrammable devices—4 patients in the nonprogrammable shunt group underwent revision for underdrainage, 2 patients had their shunts revised because of infection, and 2 patients had their shunts revised because of blockage. In the programmable shunt group, there were
4 patients (7%) who underwent shunt revision—3 patients underwent shunt revision because of infection, and 1 patient underwent revision because the shunt was blocked (Fig. 1). Patients in whom programmable shunts were implanted had lower rates of revision than did patients with nonprogrammable shunts ($p = 0.0413$).

In the nonprogrammable shunt group there were 11 patients with drainage problems; 8 had CT evidence of underdrainage and 3 had CT evidence of overdrainage. Four (50%) of 8 patients had to undergo shunt revision for underdrainage, with programmable valves being subsequently inserted. The other 4 patients with underdrainage had poor baseline neurological status and their families did not want a shunt revision. They were treated conservatively, with no improvement in neurological status. In 3 patients who had CT evidence of overdrainage the SDHs were managed conservatively, with no resolution of the hemorrhages. The SDHs were persistent, but did not increase in size. These patients' families were not willing to approve a shunt revision. In the programmable shunt group there were 11 patients with drainage problems; 6 had underdrainage and 5 had overdrainage. These problems were managed by adjusting the settings in the programmable shunts. One patient with shunt overdrainage required a bur hole evacuation of a chronic subdural hematoma. The other 10 patients were treated conservatively.

In 33 (57.9%) of 57 patients, adjustments were made to the programmable shunts. The adjustments were made for a trial of neurological improvement ($n = 21$)—this included patients with persistent headaches, drowsiness, gait disturbance, shunt underdrainage ($n = 6$), shunt overdrainage ($n = 5$), and overly sunken flap ($n = 1$). Of 33 patients who underwent adjustments in their shunt setting, 24 (72.7%) showed neurological and radiological improvement. The use of programmable shunts therefore resulted in better neurological outcomes, with fewer drainage-related problems as well as fewer instances of headaches, gait disturbance, and drowsiness than occurred with nonprogrammable shunts ($p = 0.012$). The majority of the shunts were set initially at 1.5, but after adjustments were made over a period of time to find the optimum setting, most of the shunts were at 0.5 (Fig. 2).

In 19.3% of our patients, adjustments were made to their valve settings in the outpatient clinic after they were discharged. The valve settings were turned down over the next few outpatient reviews (Fig. 3).

The cost of inserting a programmable shunt is $1242, compared with $397 for a nonprogrammable shunt, a difference of $845. If all 57 patients with programmable shunts had received nonprogrammable shunts instead, there would have been a savings of $48,165. In addition, a total of 42 adjustments were made for the 57 patients with programmable shunts, and they would have required a CT scan of the brain to recheck the size of their ventricles. A CT brain scan costs $314; 42 CT brain scans would cost $13,188. The 9 patients who had adjustments done in the outpatient clinic would require an additional 9 follow-up appointments. This would mean another $945, because each outpatient appointment costs $105. The total difference in price if nonprogrammable shunts were used would be $62,298 less. However, 11 of these 57 patients encountered problems with either overdrainage or underdrainage. A revision with a programmable shunt would have been ideal if their original devices had been nonprogrammable. The cost of a shunt revision and a 4-day stay in our hospital is $8617. The cost of the nonprogrammable valve is $397. The total cost of shunt revision for these 11 patients would have been $99,154. Overall, it would have been $36,856 more expensive if all 57 patients had nonprogrammable shunts inserted originally. This translated to a savings of...
Discussion

Aneurysmal SAH is a devastating disease that can result in a mortality rate of almost 50% and a high morbidity rate among survivors. Hydrocephalus in particular contributes significantly to the morbidity associated with SAH. The incidence of hydrocephalus has been reported to be between 6% and 37% of patients with SAH. Risk factors for hydrocephalus in patients who have suffered an SAH include increasing age, poor initial Hunt and Hess grade, Fisher Grades III and IV, presence of intraventricular hemorrhage, and postsurgical meningitis. Large third-ventricle diameter (approximately 7 mm), high CSF protein levels, higher Hunt and Hess grade, and the presence of intraventricular blood have all been shown to be predictors of shunt dependency in patients with SAH who have developed hydrocephalus. Post-SAH hydrocephalus is unique because of the variability in intracranial pressure (ICP). It is important not to assume that an elevated ICP is always present in such patients. Patients who have had an SAH may present with delayed hydrocephalus with normal or low ICP. It is therefore more difficult to manage hydrocephalus in these patients with a single fixed-pressure valve in a nonprogrammable shunt.

Shunt Complications and Revisions

Shunt failure and revision rate is one of the key factors when inserting a VP shunt. The rate of failure and revision can be as high as 16%–51.9%. The rate of complications and revisions between programmable and nonprogrammable shunts is therefore an important consideration in our study.

Previous studies reported in the literature have suggested that programmable shunts have lower revision rates than do nonprogrammable shunts because problems with over- and underdrainage can be resolved without a further shunt revision. This is especially relevant in hydrocephalus occurring post-SAH because a medium-pressure valve in a nonprogrammable shunt may not drain low- or normal-pressure hydrocephalus. We wanted to determine if this was true in our experience as well, and if programmable shunts have helped us to decrease the rate of shunt revision due to over- and underdrainage. Our data showed that programmable shunts were associated with a 3-fold lower revision rate compared with nonprogrammable shunts (7% vs 21.6%). Overdrainage and underdrainage accounted for 50% (4 of 8 patients) who underwent shunt revisions in the nonprogrammable shunt group. None of the patients in the programmable shunt group underwent shunt revision for over- and underdrainage. This resulted in a significantly lower revision rate for patients with programmable shunts (p = 0.0413).

Variability in Pressures

Patients with hydrocephalus after aneurysmal SAH are usually treated with shunt insertion either because they cannot be weaned off their external ventricular drains or because they present with delayed hydrocephalus after their drains have been removed. The ICP levels can differ in these 2 groups of patients. Whereas patients who are shunt dependent develop hydrocephalus when their external ventricular drains are challenged, patients who present with delayed hydrocephalus do not develop the condition initially when their drains are challenged and the patients are weaned off their drains. The subsequent development of delayed hydrocephalus has led to the recognition that such patients can still develop low- or normal-pressure hydrocephalus.

Instead of falling into 2 discrete groups (that is, high or medium pressure and low pressure), our patients with programmable shunts had a wide variety of optimal settings, thereby suggesting that patients with hydrocephalus after aneurysmal SAH have a wide variety of ICPs. It is difficult to achieve optimal CSF drainage with a nonprogrammable shunt, therefore accounting for the large percentage of shunt revisions attributed to drainage problems in this group (10.8% of patients). We have also found that slight adjustments in the settings of programmable shunts can sometimes successfully resolve subtle neurological problems such as headaches and cognitive defects. These problems may be a result of slight under- or overdrainage, which resolves when the drainage is optimized with adjustments of the valve settings. Such adjustments are not possible in nonprogrammable shunts.

Another interesting trend to observe from our data is that some of our optimal valve settings decrease over time. After they were discharged, 19.3% of our patients underwent adjustments to their valve settings in the outpatient clinic. During these visits the valve settings were turned down (see Fig. 3), and when the patients were subsequently reviewed they showed improvements in their neurological function, suggesting that the pressure caused by hydrocephalus post-SAH can change over time and turn into a lower-pressure form of hydrocephalus that is amenable to a lower shunt setting. This phenomenon has been previously observed, and various authors have reported that medium-pressure nonprogrammable shunts may then not resolve the hydrocephalus.

Cost Analysis

The financial cost of a shunt is an important consideration because a programmable shunt can be 2–3 times the cost of a nonprogrammable shunt. Therefore, a cost analysis is important to determine if the use of programmable shunts is economically prudent. Previous cost analyses of the programmable Codman Hakim valve have shown that despite the initial high cost of the implant, the use of programmable shunts is economically beneficial in the long term. This correlates with our cost analysis, which showed that although the cost of the programmable valve is more expensive, the intraoperative costs and the cost of hospital stay for a shunt revision are actually more significant than the cost of the programmable valve. Not included in our analysis was the cost of postoperative infections or complications that can occur after shunt revision. With these factors in mind, the use of programmable shunts is more cost-effective than nonprogrammable shunts in the management of hydrocephalus from aneurysmal SAH.
Programmable vs nonprogrammable shunt for post-SAH hydrocephalus

Conclusions

The ability to adjust pressure settings noninvasively in programmable shunts meant that shunt revisions were not needed to deal with drainage problems, thereby reducing the number of shunt revisions. This is important in the group of patients who develop hydrocephalus post-SAH, because ICPs may be variable. Adjustments made in programmable shunts also resulted in neurological improvements. Our cost-benefit analysis showed that although a programmable shunt is more expensive, the savings from not needing to revise these shunts due to drainage problems meant that they were more cost-effective overall. We therefore recommend the use of programmable shunts in the management of hydrocephalus after aneurysmal SAH.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: L. Lee, I Ng. Acquisition of data: L. Lee, King, HY Ng, KK Lee. Analysis and interpretation of data: L. Lee, King. Drafting the article: L. Lee, YP Ng. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: L. Lee. Administrative/technical/material support: Rao, HY Ng. Study supervision: I Ng.

References


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