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Exclusive use of fixed pressure valves for cerebrospinal fluid diversion in a modern adult cohort

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Abstract

Background: There is extensive debate on the role of fixed pressure shunts in the adult population. Most studies assessing fixed pressure valves do not consider the potential for changes in technique and management of shunts. We sought to examine the natural history of fixed pressure.

Methods: We conducted a retrospective chart review of 169 patients undergoing shunt placement by the senior author Daniel Wecht (DW). The etiology of shunt placement, shunt failure rates, and outcome data was assessed for each patient.

Results: Overall, 126 patients underwent initial shunt placement. Thirty-three (26.2%) patients required at least one shunt revision during follow-up. The most common cause of first time revision was mechanical shunt malfunction (13, 39.4%), followed by infection (7, 21.2%), and shunt migration (6, 18.2%). Three patients (9.1%) required revision due to misplaced catheters. Underdrainage or overdrainage of shunts each resulted in revisions for 2 (6.1%) patients. The mean follow-up length was 28.1 ± 6.1 months.

Conclusion: Fixed pressure shunts failed primarily because of shunt malfunction and occurred most commonly in patients developing hydrocephalus as a result of hemorrhage or normal pressure hydrocephalus (NPH). The overall failure rate

between these two groups was proportionally equivalent. Both overdrainage or underdrainage were found to be rare indications for revision.

Keywords: Neurology, Surgery

1. Introduction

The introduction of ventriculoperitoneal shunt insertion transformed the treatment of hydrocephalus and continues to be the most frequently used method of hydrocephalus management in both pediatric and adult patient populations [1, 2]. Gradually, fixed pressure valve systems have lost ground against newer programmable valve systems as the favored device of choice for shunt insertion. Such enhancements have been purported to provide reductions in risks for shunt malfunction and improved dynamic management of intracranial pressure [3, 4, 5]. Despite this, the rates of complication and shunt revision persist and contribute to the cost of treatment [1, 5, 6, 7, 8]. Thus, no clear consensus exists for the use of programmable over that of nonprogrammable shunts [8, 9, 10, 11].

Much of the published literature comparing the costs and clinical outcomes of programmable versus nonprogrammable shunt insertions focuses on shunt use in the pediatric hydrocephalus population [7, 12, 13]. Furthermore, few longitudinal studies have evaluated the management of hydrocephalus in adult patients with fixed shunts in a modern cohort [14, 15, 16, 17, 18]. Here, we investigated in detail the characteristics and outcomes of an adult patient population who universally received fixed valve shunt insertion as the initial treatment of hydrocephalus by a single physician.

2. Materials and methods

2.1. Data collection

We retrospectively examined clinical records within our institution from January 2000 through March 2017 of all adult patients who underwent fixed shunt placement by a single physician, Daniel Wecht (DW) for treatment of hydrocephalus at the University of Pittsburgh Medical Center. All patients received peritoneal-based catheters during their initial shunt placement. Patients that had received shunts previously by other providers were not included. Indications for shunt placement were categorized as follows: hemorrhage, normal pressure hydrocephalus (NPH), pseudotumor cerebri, tumor, and infection. The small number of patients whose etiology of hydrocephalus did not fit the above categories were grouped as others and comprise the following: traumatic brain injury, ischemic stroke, and hydrocephalus of unknown etiology.

2.2. Definitions

Patients who received shunt insertion for hydrocephalus were identified using current procedural code (CPT) 62223 as well as an electronic medical record query for the term (shunt) among patients who had been seen by the senior author. The category “hemorrhage” comprised any non-traumatic intracranial hemorrhage including subarachnoid, intraventricular, and intraparenchymal hemorrhages. Shunt revisions were defined as reoperation on a previously implanted shunt for any indication. Mechanical failure of the shunt was determined during reoperations for shunt revisions by selectively cannulating the valve and the tubing distal to the valve and assessing for the presence of drainage and normal flow using a barometer filled to 35 mm H₂O. The proximal catheter was observed after removal of the shunt valve to determine proximal obstruction. The shunt was removed and assessed for any obstruction or inability to drain properly proximally, distally, or at the valve. Any shunt that fulfilled either criteria was considered a malfunction due to mechanical failure. Overdrainage and underdrainage were determined by radiographic findings combined with clinical symptoms, such as positional headache, and the absence of any mechanical problem with the proximal shunt, distal shunt, or the valve itself during intraoperative inspection.

Patients with pseudotumor or NPH diagnoses were selected based on clinical improvement of relevant symptoms after high volume lumbar puncture or three-day lumbar drain trial. In the case of pseudotumor cerebri, the presence documented, progressive vision loss was also an indication. Patient with hemorrhage and other forms of acute hydrocephalus typically underwent prior placement of an external ventricular drain, with a gradual attempt at weaning the drain via incremental increases in the pressure level followed by a 24–48 hour clamp trial, being attempted. Patients unable to be weaned from external cerebrospinal fluid drainage had shunts placed.

3. Analysis

Statistical analysis was performed with GraphPad Prism 7.0 and IBM SPSS version 25. Chi-squared and Fisher’s exact test was performed on categorical data. Mann-Whitney tests were used for continuous variables between two groups. Kaplan-Meier curves were performed on survival data and comparisons were made using the log-rank (Mantel-Cox) test. Comparisons among three or more groups were made using Kruskal-Wallis test followed by Dunn’s post-hoc test. The level of significance was $p < 0.05$.

4. Results

We collected data from 169 patients who had undergone insertion of fixed shunts between 2000 and 2017 for the treatment of hydrocephalus. We excluded 43 patients

who had been previously shunted, resulting in 126 patients shunted by a single physician. One hundred twenty-three of 126 (97.6%) of patients received parietal ventriculoperitoneal (VP) shunting. Occipital and frontal shunting were performed in 2 (1.6%) and 1 (0.8%) of initial operations, respectively. One hundred twenty-three of 126 (97.6%) operations used Pudenz valves. One operation involved insertion of a Delta valve and the remaining two patients received Heyer-Schulte valves. The majority of valve pressures were set at medium (118 of 125, 94.4%). Seven of 125 were set at low (5.6%). These patients were subsequently categorized into etiologies for hydrocephalus: hemorrhagic, NPH, tumor, pseudotumor cerebri, infection, and others (see below). Of the patients with low valve pressure settings, 4 of 7 (57.1%) fell into the hemorrhagic group, 2 of 7 (28.6%) had tumors, and 1 of 7 (14.3%) had an infection.

The distribution of patients across hydrocephalus etiologies is as follows: hemorrhagic (54 of 126, 42.9%), NPH (48 of 126, 38.1%), tumor (8 of 126, 6.3%), pseudotumor cerebri (7 of 126, 5.6%), infection (1 of 126, 0.8%), and others (8 of 126, 6.3%) (Table 1). Forty-eight (38%) patients were male whereas 78 (62%) were female. Further details of the distribution of male and female patients across etiologies of hydrocephalus can be found in Table 2. When categorized by etiology, we found the following mean ages of male and female patients respectively: 58.4 ± 6.1 vs. 56.8 ± 4.7 years (hemorrhagic), 74.9 ± 3.8 vs. 71.3 ± 3.3 years (NPH), 59.8 ± 15.3 vs. 71.7 ± 23.2 years (tumor), and 52.7 ± 15 vs. 58.4 ± 8 years (other). Only females exhibited pseudotumor cerebri at a mean age of 31 ± 5.1 years. A single female patient with infectious etiology was 75 years old.

No differences in proportion of shunt failures were found between males and females (Fisher's exact test, $p = 0.5467$). However, when stratified by etiology the proportion of shunt revisions was greater in female than in male patients with NPH ($p = 0.0158$, Table 2). Mean follow up time for all patients was 28.1 ± 6.1 months

Table 1. Distribution of patients receiving fixed valve shunts and shunt revisions. Curved bracketed values indicate proportion of total. Follow up time is indicated in months as mean ± standard error.

Etiology	Patient number (%)	Shunt revisions (%)	Follow up time
Hemorrhage	54 (42.9)	14 (42.4)	22.5 ± 5.2
NPH	48 (38.1)	13 (39.4)	28.1 ± 7.1
Infection	1 (0.8)	0 (0)	1.7
Other	8 (6.3)	4 (12.1)	43.6 ± 17.4
Pseudotumor cerebri	7 (5.6)	2 (6.1)	7.1 ± 4.7
Tumor	8 (6.3)	0 (0)	65.9 ± 64.5
Total	126 (100)	33 (100)	28.1 ± 6.1

Table 2. Distribution of shunt revisions across genders and etiology of hydrocephalus. NA indicates not applicable.

	Male			Female			P value
	Revisions	None	Total	Revisions	None	Total	
Hemorrhage	5	19	24	9	21	30	0.328
NPH	8	8	16	5	27	32	0.0158
Infection	0	0	0	0	1	1	NA
Other	2	1	3	2	3	5	NA
Pseudotumor cerebri	0	0	0	2	5	7	NA
Tumor	0	5	5	0	3	3	NA
Total	15	33	48	18	60	78	

(Table 1). By etiology, the follow up times are listed: 22.5 ± 5.2 months (hemorrhagic), 28.1 ± 7.1 months (NPH), 7.1 ± 4.7 months (pseudotumor cerebri), 65.9 ± 64.5 months (tumor), and 43.6 ± 17.4 months (other). A single patient with infectious etiology followed up in 1.7 months.

4.1. Shunt revision

Thirty three of 126 patients (26.2%) required at least one shunt revision (Table 3), with mechanical shunt malfunction (13 of 33, 39.4% of failures) being the most common reason for failure. Six of 13 malfunctions resulted from mechanical failure at the valve, 2 of 13 occurred proximally, and 5 of 13 occurred distally. Shunt infection was the second most common reason for shunt revisions (7 of 33, 21.2% of failures, 5.6% of all patients). Of note, antibiotic impregnated catheters are not routinely used at our institution in adults. Shunts migration occurred in 6 of 33 (18.2% of failures) of patients. Misplaced shunts accounted for three of 33 (9.1% of failures) of shunt revisions. Both overdrainage and underdrainage each resulted in 2 (6.1% of failures) shunt revisions, and all 4 patients whose shunts failed for this reason had NPH. Importantly, all shunts were functional in patients experiencing overdrainage and underdrainage.

Table 3. Distribution of number of shunt revisions.

Number of revisions	Number of patients (%)
1	19 (57.6)
2	10 (30.3)
3	1 (3)
4	2 (6.1)
5	1 (3)
Total	33 (100)

When stratified by etiology of hydrocephalus compared to number of patients requiring at least one revision, a large percentage of patients (14 of 33, 42.4% of failures) whose shunts required revision developed hydrocephalus initially as a result of hemorrhage. A similar proportion was found in patients who required treatment for NPH (13 of 33, 39.4% of failures). Two patients (6.1% of failures) with pseudotumor cerebri required treatment shunt failure, while no shunts failed in patients treated for hydrocephalus due to tumor or infection. Four patients (12.1%) whose etiology of hydrocephalus did not fall in the above categories required shunt revision (Table 1).

When considering shunt revisions as a fraction of the total number of shunt placements by etiology, shunt revisions occurred in similar proportions among those with hemorrhage (14 of 54, 25.9%), NPH (13 of 48, 27.1%), and pseudotumor cerebri (2 of 7, 28.6%). Two of 4 (50%) patients categorized as “others” required shunt revision. Zero patients in either “infection” or “tumor” groups required revision ($p = 0.165$). Furthermore, the rate of revisions between the hemorrhage and NPH groups that received fixed shunts were not different ($p = 0.873$, Fig. 1).

Nineteen of 33 patients (57.6%) required a single revision. Ten of 33 patients (30.3%) required two shunt revisions during follow up. Four of 33 patients (12.1%) required three or more revisions. Together, shunt revisions occurred at an average rate of 1.7 ± 0.2 per patient among those requiring at least one revision.

4.2. Presenting symptoms

Of 126 patients who received insertion of fixed VP shunt, we were able to characterize the preoperative symptomology of 109 patients: 41 from hemorrhagic, 46 from NPH, 1 from infection, 8 from other, 7 from pseudotumor cerebri, and 8 from tumor. Across all etiologies, 69 of 109 patients (63.3%) exhibited decreased cognitive deterioration, 61 (56%) presented with gait disturbances, 34 (31.2%) presented with urinary incontinence, and 31 (28.4%) presented with headaches. A smaller number of patients presented with the following symptoms: decreased wakefulness (17 of 109, 15.6%); nausea and/or vomiting (11 of 109, 10.1%); vertigo (5 of

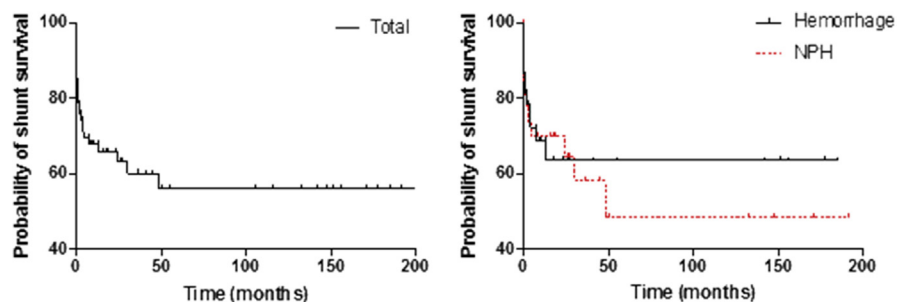


Fig. 1. Survival curve in all patients (Left) or compared between Hemorrhagic and NPH groups (Right). Log-rank test was performed.

109, 4.6%), blurry vision (8 of 109, (7.3%), or papilledema (6 of 109, 5.5%). No patients presented pre-operatively with double vision. By etiology, the most common symptoms presented within the hemorrhagic group were headaches (23 of 41, 56%) and cognitive decline (22 of 41, 53.7%). The most common symptoms within the pseudotumor cerebri group were headaches (4 of 7, 57.1%), blurry vision (7 of 7, 100%), and papilledema (6 of 7, 85.7%). The majority of patients within the tumor group presented with cognitive decline (6 of 8, 75%) and gait instability (3 of 8, 37.5%) (Table 4).

4.3. Post-operative symptom effect

We found that 47 of 126 (37.3%) patients passed away at the time the data was collected. No deaths were associated with the peri- or post-operative surgical complications. Of those patients the mean survival length from the time of shunt insertion until mortality date was 50.3 ± 6.5 months.

We next characterized the resolution of symptomology patient by patient following shunt insertion and found 74 patients who met criteria to compare their pre-operative and post-operative symptomology: 23 from hemorrhage, 33 from NPH, 1 from infection, 5 from other, 6 from pseudotumor cerebri, and 6 from tumor. Fixed shunt insertion was found to resolve headaches in 13 of 17 patients (76.5%), blurry vision in 5 of 6 patients (83.3%), papilledema in 5 of 6 patients (83.3%), cognitive decline in 39 of 43 patients (90.7%), decreased wakefulness in 8 of 9 patients (88.9%), gait instability in 35 of 43 patients (81.4%), urinary incontinence in 19 of 22 patients

Table 4. Summary of presenting symptoms by etiology. Values indicate number of patients with symptoms. Parentheses indicate the percent of patients within categories.

Presenting symptoms	Hemorrhage (n = 41)	NPH (n = 46)	Infection (n = 1)	Other (n = 8)	Pseudotumor cerebri (n = 7)	Tumor (n = 8)	Total
Headache	23 (56.1)	2 (4.3)	0	1 (12.5)	4 (57.1)	1 (12.5)	31
Double Vision	0	0	0	0	0	0	0
Blurry Vision	1 (2.4)	0	0	0	7 (100)	0	8
Papilledema	0	0	0	0	6 (85.7)	0	6
Cognitive Decline	22 (56.7)	35 (76.1)	1 (100)	4 (50.0)	1 (14.3)	6 (75.0)	69
Decreased Wakefulness	13 (31.7)	2 (4.35)	0	2 (25.0)	0	0	17
Gait Instability	7 (17.0)	44 (95.7)	1 (100)	6 (75.0)	0	3 (37.5)	61
Urinary incontinence	3 (7.3)	29 (63.0)	0	1 (12.5)	0	1 (12.5)	34
Nausea/vomiting	11 (26.8)	0	0	0	0	0	11
Vertigo	2 (4.9)	1 (2.2)	0	1 (12.5)	0	1 (12.5)	5

(86.4%), nausea/vomiting in 3 of 4 patients (75%), and vertigo in 2 of 3 patients (66.7%). Further details regarding the resolution of symptoms by etiology are found in Table 5.

5. Discussion

Although hydrocephalus arises from diverse etiologies, VP shunt insertion continues to be the most frequently used treatment in both the pediatric and adult patient populations [5, 6, 19]. Despite significant technological advancements and constructions of ventriculoperitoneal shunts, the rates of complication following shunt insertion remain considerable and contribute to the excessive cost of treatment [3, 20, 21, 22]. Here, we detailed the use of fixed shunts in 126 patients from 2000 – 2017 from a single physician. A major concern for the use of fixed shunts is the complication of overdrainage or underdrainage of cerebrospinal fluid (CSF) [11]. We found that 26.2% of patients with a fixed shunt required at least one revision, and the most common cause of shunt revision was due to malfunction, making up 39.4% of failures. This is consistent with previous studies [19, 23, 24, 25].

Etiology of hydrocephalus has also been found to be correlated with frequency of shunt revisions. In our study, patients in either hemorrhage or NPH categories accounted for the majority of shunt revisions (42.4% and 39.4%, respectively). However, the proportion of shunt failures were similar in either groups (25.9% and 27.1%, respectively). This may be explained by the differences in number of patients in each of our categories. Nevertheless, the low proportion of failures in those shunted for

Table 5. Summary of resolved symptoms following shunt insertion by patient. Parentheses indicate the percent of resolved symptoms within each category.

Resolved symptoms	Hemorrhage (n = 23)	NPH (n = 33)	Infection (n = 1)	Other (n = 5)	Pseudotumor cerebri (n = 6)	Tumor (n = 6)	Total
Headache	11 of 12 (91.7)	0 of 1	0	0	2 of 3 (66.7)	0 of 1	13 of 17 (76.5)
Double Vision	0	0	0	0	0	0	0
Blurry Vision	0	0	0	0	5 of 6 (83.3)	0	5 of 6 (83.3)
Papilledema	0	0	0	0	5 of 6 (83.3)	0	5 of 6 (83.3)
Cognitive Decline	7 of 9 (77.8)	23 of 24 (95.8)	1 of 1 (100)	3 of 3 (100)	1 of 1 (100)	4 of 5 (80.0)	39 of 43 (90.7)
Decreased Wakefulness	6 of 7 (85.7)	2 of 2 (100)	0	0	0	0	8 of 9 (88.9)
Gait Instability	3 of 3 (100)	25 of 31 (80.6)	1 of 1 (100)	4 of 5 (80.0)	0	2 of 3 (66.7)	35 of 43 (81.4)
Urinary incontinence	1 of 1 (100)	16 of 19 (84.2)	0	1 of 1 (100)	0	1 of 1 (100)	19 of 22 (86.4)
Nausea/vomiting	3 of 4 (75)	0	0	0	0	0	3 of 4 (75)
Vertigo	1 of 1 (100)	1 of 1 (100)	0	0	0	0 of 1	2 of 3 (66.7)

NPH is comparable to those found in previous studies [25, 26]. Overdrainage and underdrainage reflected only 6.1% of failures, respectively (2 of 33). Interestingly, all four patients suffering from symptoms due to overdrainage or underdrainage had an initial diagnosis of NPH. Those with symptoms of underdrainage were revised to a low pressure fixed valve with no further complications, whereas the two patients with overdrainage issues subsequently received a Strata valve set to 2.5 and Delta valve set to 2.5.

Shunt insertion was found to resolve a large proportion of presenting symptoms. Nearly all patients with hemorrhagic hydrocephalus experienced headache resolution as well as improvements in cognitive decline and decreased wakefulness. Patients with NPH primarily presented with cognitive decline, gait instability and urinary incontinence that were also resolved. Hydrocephalus due to pseudotumor cerebri caused primarily headaches, blurry vision, and papilledema. Shunt insertion resolved these symptoms in the majority of patients.

A major concern for the use of programmable shunts is its significant cost compared to that of fixed shunts. At our institution, the total shunt supply implant cost and direct supply expenses for programmable shunts were more expensive than using fixed valves [27]. The lack of consensus over the cost-benefit of using a more expensive programmable valve has generally been mixed.

5.1. Limitations

Several limitations of our study may have biased our results. Our study retrospectively reviews the data of patients receiving fixed shunts. We therefore cannot randomize prospectively matched groups, subjecting our analysis to potential confounding bias. Furthermore, data was collected from a single institution that predisposes our study to selection bias based upon the demographics at this institution.

6. Conclusion

Our study characterizes the clinical outcomes of a modern cohort of adult patients receiving fixed shunts by a single physician at our institution for the treatment of hydrocephalus due to diverse etiologies. We further compare the clinical outcomes for patients receiving fixed shunts to those that of programmable shunts. From the patient population evaluated in this study, hydrocephalus occurred most frequently as a result of NPH or hemorrhage, and the revision rates were similar between these two groups. Shunt malfunction was found to be the primary reason for failure. The proportion of failed shunts remains considerable and comparable to those in decades past. Given the experience of the physician performing these shunt insertions, our study highlights the need for improvements in the design of fixed shunt valve designs to reduce failures resulting from malfunction.

Declarations

Author contribution statement

Michael M. McDowell: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Michael C. Chiang: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Nitin Agarwal, Robert M. Friedlander: Analyzed and interpreted the data; Wrote the paper.

Daniel A. Wecht: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

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The authors declare no conflict of interest.

Additional information

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