Ventriculoperitoneal Shunt Surgery Outcome in Adult Transition Patients With Pediatric-Onset Hydrocephalus

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BACKGROUND: Ventriculoperitoneal shunting remains the most widely used neurosurgical procedure for the management of hydrocephalus, albeit with many complications.
OBJECTIVE: To review and assess the long-term clinical outcome of ventriculoperitoneal shunt surgery in adult transition patients with pediatric-onset hydrocephalus.
METHODS: Patients 17 years or older who underwent ventriculoperitoneal shunt placement for hydrocephalus during their pediatric years (younger than 17 years) were included. Medical charts, operative reports, imaging studies, and clinical follow- up evaluations were reviewed and analyzed retrospectively.
RESULTS: A total of 105 adult patients with pediatric-onset hydrocephalus were included. The median age of the patients was 25.9 years. The median age at the time of the initial ventriculoperitoneal shunt placement was 1.0 year. The median follow-up time for all patients was 17.7 years. The incidence of shunt failure at 6 months was 15.2%, and the overall incidence of shunt failure was 82.9%. Single shunt revision occurred in 26.7% of the patients, and 56.2% had multiple shunt revisions. The cause of hydrocephalus was significantly associated with shunt survival for patients who had shunt failure before the age of 17 years. Being pediatric at first shunt revision, infection, proximal shunt complication, and other causes were independently associated with multiple shunt failures.
CONCLUSION: The findings of this retrospective study show that the long-term ventriculoperitoneal shunt survival remains low in adult transition patients with pediatric-onset hydrocephalus.

KEY WORDS: Cerebrospinal fluid, Shunt complication, Shunt failure, Shunt revision, Shunt surgery, Ventriculoperitoneal shunting

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Hydrocephalus is a heterogeneous group of disorders that follows children into adulthood.[1,2] It generally results from a disturbance of production, flow, or absorption of cerebrospinal fluid (CSF), leading to an excessive accumulation of this fluid in the intracranial cavity of the brain.[3] The clinical presentation depends on the age at onset, and its most deleterious effects result from damage to neuronal cells caused by increased intracranial pressure.[4] This necessitates the urgent relief of intracranial pressure to prevent or minimize hydrocephalus-induced neurological deficits.

ABBREVIATIONS: CSF, cerebrospinal fluid; **ETV,** endoscopic third ventriculostomy; **LSUHSC-S,** Louisiana State University Health Sciences Center–Shreveport; **VP,** ventriculoperitoneal

The management of pediatric hydrocephalus patients who transitioned to adults is a growing concern in neurosurgery.[5] Clinical studies on outcomes after ventriculoperitoneal (VP) shunt surgery are scarce; specifically, there are no reports in the literature on the management of adult-transition patients with pediatric-onset hydrocephalus. Implantation of a VP shunt is the most widely used treatment for the management of hydrocephalus.[6,7] Thus, a patient with pediatric-onset hydrocephalus will remain shunt dependent during adulthood. However, endoscopic third ventriculostomy (ETV), a minimally invasive procedure, has been developed as an alternative to shunt surgery for the management of certain

patients with hydrocephalus.[8-10] The clinical advantage of ETV is that it allows the ventricular CSF to bypass anatomic obstructions through the hole created in the floor of the third ventricle and enters directly into subarachnoid space where it absorbs eventually. However, determining the appropriate patients suitable for ETV appears to be challenging, particularly with regard to the effect of age and etiology.[11-15] In addition, ETV is associated with complications, some of which are quite serious.[16-22] Moreover, the relative effectiveness of these 2 interventions remains a matter of ongoing debate and needs further evaluation.

Currently, the exact number of adult patients with pediatric-onset hydrocephalus is unknown; however, the condition is not rare. In the United States, hydrocephalus accounts for 70 000 hospital admissions annually.[23] As a result, approximately 30 000 CSF shunts are placed each year, which costs billions of dollars annually to provide health care for these patients.[23-25] Although the placement of a VP shunt is the long-standing treatment of choice for hydrocephalus, complications related to VP shunt failure continue to occur with distressing frequency. Causes of shunt failure include obstruction, infection, mechanical disconnection, and overdrainage.[25-28] The findings from the long-term studies suggest that about 45% to 59% of all patients, regardless of age, experience multiple shunt failures requiring a shunt revision with surgical interventions.[29,30] Recently, we showed that VP shunt surgery is effective with an overall shunt failure rate of 27.8% in patients with intracranial tumors.[31] Using a conceptual model, the analysis of the pooled data from multiple studies demonstrated that shunt survival rates in children (younger than 17 years) and adults (older than 17 years) for 1 year were 64.2% and 80.1%, respectively, and for 5 years were 49.4% and 60.2%, respectively, with the median shunt survival of 4.9 and 7.3 years, respectively.[32] Similarly, the shunt design trial demonstrated that the overall shunt survival was 62% at 1 year, and 41% at 4 years in pediatric patients.[33]

Earlier studies suggest that increasing the number of previous revisions and shorter time to first revision increase the risk of shunt complications in patients with hydrocephalus.[25,34,35] The factors that influence the shunt failures or the risk of shunt complications have yet to be fully investigated. In this study, we retrospectively analyzed the adult patients with pediatric-onset hydrocephalus from the Louisiana State University Health Sciences Center–Shreveport (LSUHSC-S) database to examine the incidence of VP shunt failures and complication rates. The outcomes of this retrospective study may help improve the surgical management of adult-transition patients with pediatric-onset hydrocephalus.

MATERIALS AND METHODS

The LSUHSC-S is the primary neurosurgical referral center for the state of Louisiana. The study was approved by the institutional review board of LSUHSC-S. Using the database (MD Analyze, Medtech Global Ltd., South Melbourne, Victoria, Australia), patients with hydrocephalus were identified initially with International Classification of Diseases 9th Revision diagnostic codes for hydrocephalus. Patients who underwent primary shunt implantation for hydrocephalus before October 1990 (n = 80) as well as after October 1990 to February 2010 (n = 935, study cutoff date) were screened for the study eligibility. The primary eligibility criteria of the study were that patients must be 17 years or older and should have undergone primary shunt implantation during their pediatric years (before 17 years of age) (Figure 1). To comply with the Health Insurance Portability and Accountability Act, confidentiality of information was secured by using text encryption, password protection, and limited personnel involvement.

For the study period, medical charts, operative reports, imaging studies, and clinical follow-up evaluations were reviewed retrospectively for all transition patients with pediatric-onset hydrocephalus who underwent VP shunt surgery. Information on each patient, including age, sex, ethnicity, etiology of hydrocephalus, type of hydrocephalus, date of shunt placement, date of first and subsequent shunt replacement or revisions, stealth-guided navigation, valve type, date of last follow-up, and cause of shunt malfunction or failure, was collected from patient records.

The primary outcome of interest was the overall shunt revision rate and the median time to shunt failure or revision in adult hydrocephalus patients. The time to shunt failure was defined as the time from the date of the shunt placement to the date of the first shunt revision or failure. The overall shunt failure was defined as either revision or replacement after the shunt insertion. The patient diagnoses were grouped into congenital, tumors/cysts, and other etiologies. Congenital hydrocephalus was defined

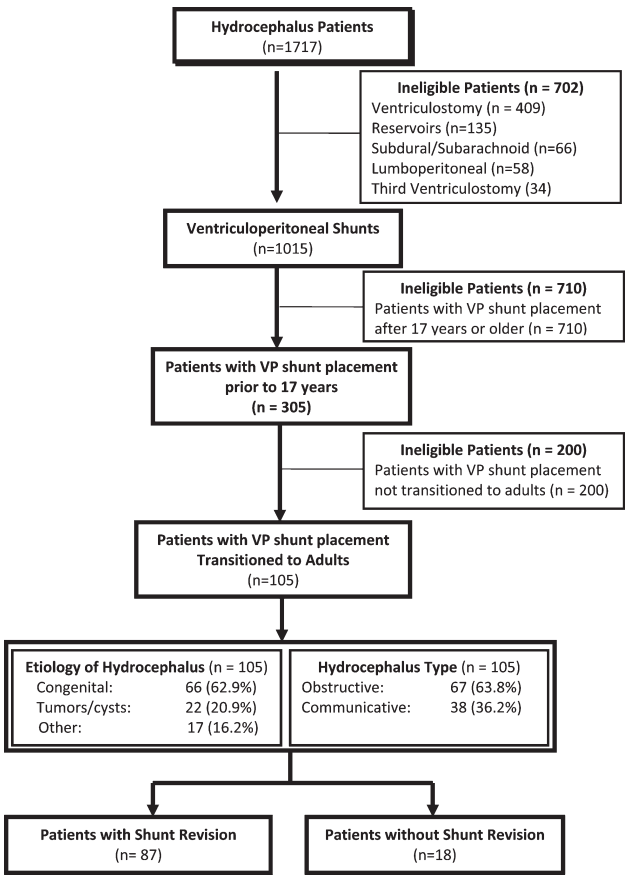

FIGURE 1. *Flowchart depicting the selection of patients for the study.*

as increased retention of CSF in the ventricles associated with ventricular dilation diagnosed at the time of birth and included Dandy-Walker syndrome, spinal dysraphism, Chiari malformation, and aqueductal stenosis. Other etiology included subarachnoid hemorrhage, post-craniotomy, post-trauma, intracranial hemorrhage, subdural hemorrhage, intraventricular hemorrhage, and meningitis.

Statistical Procedures

Multiple logistic regression analysis was used to determine independent risk factors for shunt failure and having multiple revisions (among patients with shunt failure). The Wilcoxon rank sum test was used to compare groups that are significantly different on shunt failure rate on average number of shunt revisions or failures. The Cox proportional hazards regression model was used to determine independent significant factors for overall shunt survival. The log-rank test was used to compare survival rates and median shunt survival time among categories of risk factors for overall shunt failure. The Kaplan-Meier method of survival analysis was used to estimate 6-month, 1-year, 5-year, 10-year, 20-year, and maximum follow-up time shunt survival (revision free) rates.

RESULTS

A total of 1717 patients who underwent treatment for hydrocephalus were initially screened, and 1015 patients with VP shunt placement were identified. Of the 1015 patients, 305 (30.0%) were pediatric patients (younger than 17 years), and 710 (70.0%) were adults (older than 17 years) at the time of the initial shunt placement. Among 305 pediatric patients, 200 were excluded from the study because of the fact that these patients are still in their pediatric years (younger than 17 years) and yet to be transitioned to adults. The remaining 105 patients who transitioned to adulthood (older than 17 years) were included in the study (Figure 1).

Of the 105 patients, 54 (51%) were male and 51 (49%) were female. Sixty percent of the patients were white and 40% were African American. The median age of the patients was 25.9 years (range, 17.3-56.7 years). The most common etiologies of hydrocephalus in the patient sample include congenital (63%), tumors and cysts (21%), and other (16%). Obstructive hydrocephalus was present in 64% and communicating hydrocephalus accounted for 36% of the patients (Table 1). There were 11 deaths (10.5%) observed during the follow-up of the study. The median follow-up time for all patients was 17.7 years (range, 0-44.2 years).

Of the 105 patients with VP shunt placement, 87 (82.9%) experienced 1 or more shunt failures requiring shunt revision(s). Single shunt revision occurred in 28 patients (26.7%) and multiple shunt revisions occurred in 59 patients (56.2%) after initial shunt placement. The median number of revisions per patient was 2 (range, 0-15). The median time to shunt revision was 10.3 years (range, 0-42 years). The median age at first shunt revision was 16.0 years (range, 0-50.6 years) (Table 2).

Among the 87 patients who experienced shunt failures, 48 (45.7%) had their first shunt revisions during their pediatric years (younger than 17 years), and 39 patients (37.1%) had their first shunt revisions after transitioning to adulthood (older than 17 years). Of the 87 patients who experienced shunt revisions, 16 (15.2%) had shunt revisions within the first 6 months after initial shunt placement. Overall, 18 (17.1%), 29 (27.6%), 38 (36.2%), and 66 (62.9%) patients experienced shunt failures requiring shunt revisions within 1 year, 5 years, 10 years, and 20 years, respectively, after initial shunt placement (Table 2).

The results in Table 3 list the most common reasons for shunt revisions in adult patients with pediatric-onset hydrocephalus. A total of 278 shunt revisions occurred in 87 patients because of various causes such as obstruction, infection, overdrainage, mechanical, and other shunt complications. Obstruction caused a total of 141 shunt revisions in 68 patients (64.8%). Infection caused a total of 33 revisions in 22 patients (21%). Proximal shunt complications caused a total of 87 shunt revisions in 54 patients (51.4%). Shunt system replacement resulted in 73 total shunt revisions in 49 patients (46.7%). Other shunt complications resulted in a total of 73 shunt revisions in 48 patients (45.7%). Other complications of the shunt include shunt disconnection, shunt catheter leakage/breakage, shunt extrusion, shunt catheter migration, and shunt catheter protrusion.

TABLE 1. Demographics of Pediatric Hydrocephalus Patients Transitioned to Adults[a]

Demographics	Patients
Total no. (%) of patients	105 (100)
Sex, no. (%)	
Male	54 (51.4)
Female	51 (48.6)
Ethnicity, no. (%)	
White	63 (60.0)
African American	42 (40.0)
Median age, y (as of study date)	25.9
Range	17.3-56.7
Median age at shunt placement, y	1.0
Range	0-17
Etiology, no. (%)	
Congenital	66 (62.9)
Tumors/cysts	22 (20.9)
Other	17 (16.2)
Hydrocephalus type, no. (%)	
Obstructive	67 (63.8)
Communicative	38 (36.2)
Procedure before VP shunt insertion, no. (%)	
Yes	11 (10.5)
No	94 (89.5)
Program valve, no. (%)	
Yes	20 (19.0)
No	85 (81.0)
Navigation, no. (%)	
Yes	5 (4.8)
No	100 (95.2)
Death during follow-up, no. (%)	11 (10.5)

[a]VP, ventriculoperitoneal.

TABLE 2. Shunt Revision in Adult Transition Patients With Pediatric Onset of Hydrocephalus

Shunt Revision type	Patients, n = 105)
Patients with shunt revisions, no. (%)	87 (82.9)
Patients with single shunt revision, no. (%)	28 (26.7)
Patients with multiple shunt revisions, no. (%)	59 (56.2)
Median number of revisions per patient (range)	2 (0-15)
Median time to shunt revision (range), y	10.3 (0-42)
Median age at 1st shunt revision (range), y	16.0 (0-50.6)
Patients with first shunt revision at age $<$ 17.0 y, no. (%)	48 (45.7)
Patients with first shunt revision at age $\geq$ 17.0 y, no. (%)	39 (37.1)
Patients with shunt revision within the first 6 mo, no. (%)	16 (15.2)
Patients with shunt revision within 1 y, no. (%)	18 (17.1)
Patients with shunt revision within 5 y, no. (%)	29 (27.6)
Patients with shunt revision within 10 y, no. (%)	38 (36.2)
Patients with shunt revision within 20 y, no. (%)	66 (62.9)

Using separate univariate analyses with the χ^2 test, congenital etiology and communicative hydrocephalus type were identified as the risk factors significantly associated with overall shunt failure (Table 4). Patients with congenital hydrocephalus had a higher shunt failure rate than those with tumors/cysts and other etiology (93.9% vs 64.1%, $P < .01$). Because there were no significant differences in the shunt revision rate between the tumors/cysts and other etiologies, the patients with these etiologies were merged into 1 group and compared with those with congenital hydrocephalus. In addition, univariate analysis of the data showed that patients with communicative hydrocephalus experienced more shunt revisions than those with obstructive hydrocephalus (94.7% vs 76.1%, $P = .02$). The findings from the Wilcoxon rank sum test indicate that the median number of revisions was significantly higher for a congenital etiology than for tumor/cysts or other etiology (3.0 vs 1.0, $P < .01$).

To better understand the risk of shunt failure in adult patients with pediatric-onset hydrocephalus, we assessed the shunt failure history and associated risk factors before age 17 years and after age 17 years. The results from this analysis are presented in Table 4. Among the 87 patients with shunt failure, 48 patients had their first shunt failure before age 17 (pediatric years) and 39 had had their first shunt failure after or at age 17 (adult years). The median number of shunt revisions during the pediatric years (younger than 17 years) was 3 (range, 1-15 years) and during the adult years (older than 17 years) was 2 (range, 1-9 years). The median time to shunt revision was 4.1 years (range, 0-16.6 years) for the patients during pediatric years (younger than 17 years) and 21.3 years (range, 0.1-42.0 years) for the patients during adult years (older than 17 years). The median age at first shunt revision was 8.5 years (range, 0-16.8 years) for the patients during pediatric years (younger than 17 years) and 23.2 years (range, 17-50.6 years) for the patients during adult years (older than 17 years). Only

TABLE 3. Causes of Shunt Revision Among Patients and Among Shunt Revisions

Cause/Complication	Among Patients, N = 105, no. (%)	Among Shunt Revisions, n = 278, no. (%)[a]
Obstruction	68 (64.8)	141 (50.8)
Infection	22 (21.0)	33 (11.9)
Overdrainage	10 (9.5)	18 (6.5)
Proximal shunt complication	54 (51.4)	87 (31.3)
Distal shunt complication	42 (40.0)	50 (18.0)
Valve replacement	54 (51.4)	62 (22.3)
Shunt system replacement	49 (46.7)	73 (26.3)
Shunt system removal	32 (30.5)	49 (17.6)
Externalization of shunt	23 (21.9)	28 (10.1)
Shunt adjustment	14 (13.3)	17 (6.1)
Other shunt complications[b]	48 (45.7)	73 (26.3)

[a]A total of 278 shunt revisions occurred from various causes/complications in 87 patients.
[b]Other complications of the shunt include shunt disconnection, shunt catheter leakage/breakage, shunt extrusion, shunt catheter migration, and shunt catheter protrusion.

TABLE 4. Summary Statistics on Characteristics of Patients With Shunt Failure and Comparison of Overall Shunt Failure Rate by Etiology and Hydrocephalus Type

Variable/Group	Patients With Shunt Failure	Patients With Shunt Failure Before Age 17 y	Patients With Shunt Failure After Age 17 y
Patients with shunt revision	87	48	39
Median number of shunt revisions (range)	2 (1-15)	3 (1-15)	2 (1-9)
Median time to shunt revision (range), y	10.3 (0-42)	4.1 (0-16.6)	21.3 (0.1-42.0)
Median age at first shunt revision (range), y	16.0 (0-50.6)	8.5 (0-16.8)	23.2 (17-50.6)
Etiology of hydrocephalus, no. (%)			
Congenital (n = 66)[a]	62 (93.9)	39 (59.1)	23 (34.8)
Tumors and cysts/other (n = 39)[a]	25 (64.1)	9 (23.1)	16 (41.0)
Comparison *P* value	<.01[b]	<.01[b]	.53[d]
Hydrocephalus type, no. (%)			
Communicative (n = 38)[a]	36 (94.7)	21 (55.3)	15 (39.5)
Obstructive (n = 67)[a]	51 (76.1)	27 (40.3)	24 (35.8)
Comparison *P* value	.02[c]	.14[d]	.71[d]

[a]Represents the total number of patients.
[b]Signicant at 1% level (*P* value <.01).
[c]Signicant at 5% level (*P* value <.05).
[d]Not signicant at 5% level (*P* value >.05).

congenital etiology was significantly associated with shunt failure before age 17 ($P < .01$). Neither etiology nor hydrocephalus type was a significant factor for shunt failure at or after age 17.

Risk factors for multiple shunt failures/revisions were determined among the 87 patients who had at least 1 shunt revision. Results from the multiple logistic regression analysis demonstrate that being pediatric at first shunt revision, infection, and proximal and other shunt complications were independently associated with multiple shunt revision (Table 5). Adjusted for the significant effects of infection and proximal and other shunt complications, patients who experienced shunt failure before age 17 were more likely to have multiple shunt failures than patients whose first shunt failure occurred at or after age 17. The odds of multiple revisions among patients who were pediatric at their first shunt failure were 3.7 times higher than those whose first shunt failure occurred as adults. Adjusted for the effects of other significant factors, the odds of multiple shunt revisions among patients who had infection and proximal and other shunt complications were 4.9, 10.4, and 3.7 times higher, respectively, than those who did not experience the indicated complications (Table 5).

Overall shunt survival at 6 months, 1 year, 5 years, 10 years, and 20 years after shunt placement was 84.8%, 82.9%, 72.4%, 63.8%, and 37.1%, respectively. The only independent significant risk factor for both 10-year and 20-year shunt failures was being pediatric at first shunt revision. At 10 years, patients who were pediatric at first revision had lower shunt survival rate than those who were adults (31.7% vs 91.9%, $P < .01$). At 20 years, the estimated shunt survival rates were 0% and 56.8% among patients who were pediatric and adult at first shunt revision, respectively ($P < .01$).

The results in Table 6 indicate that the median shunt survival for all patients was 12.4 years (range, 8.9-16.4 years) and for patients who had their shunt revision before and after the age of 17 years, the median shunt survival was 15.6 years (range, 10.3-17.9 years) and 22.3 years (range, 18.6-25.1 years), respectively. Because etiology was the only risk factor observed to be significantly associated with shunt failure, the impact of congenital and tumors/cysts or other etiologies were compared among the patients. Significant differences in the median shunt survival by etiology were observed only for patients who had their

TABLE 5. Independent Risk Factors for Multiple Revisions Among Patients With Shunt Failure

Risk Factor	Odds Ratio	95% Condence Interval	*P*
Infection	4.9	1.2-20.0	.03
Proximal complication: yes vs no	10.4	3.0-35.7	<.01
Pediatric at first revision: yes vs no	3.7	1.2-11.1	.02
Other shunt complications: yes vs no[a]	3.7	1.2-11.2	.02

[a]Other complications of the shunt include shunt disconnection, shunt catheter leakage/breakage, shunt extrusion, shunt catheter migration, and shunt catheter protrusion.

TABLE 6. Median Shunt Survival in Adult-Transition Patients: Comparison of Pediatric (<17) and Adult (>17) Years by Etiology[a]

Variable/Group	All Patients, N = 105	Patients Before Age 17 y, n = 66	Patients After Age 17 y, n = 39
Median shunt survival (range), y	12.4 (8.9-16.4)	15.6 (10.3-17.9)	22.3 (18.6-25.1)
Median shunt survival by etiology (range), y			
Congenital (n = 66)	11.3 (7.2-15.3)	12.4 (7.2-16.5)	22.3 (18.6-25.1)
Tumors and cysts/other (n = 39)	17.0 (10.1-23.9)	NR	23.9 (17.0-25.4)
Comparison *P* value	.20[b]	.02	.49[b]

[a]NR, median survival for patients with tumors and cysts/other etiology was not reached because <50% of the patients experienced shunt failure.
[b]Not signicant at 5% level (*P* value >.05).

shunt failure before the age of 17 years. Etiology had no impact on shunt survival for patients who had their shunt failure after the age of 17 years. The data in Figure 2A, B represent the Kaplan-Meier shunt survival curves for all patients as well as patients who had their shunt failure before the age of 17 years. The overall survival was significantly affected by the etiology of hydrocephalus only for patients who had their shunt failure before the age of 17 years (Figure 3B) but not for all patients (Figure 3A).

DISCUSSION

As the survival of pediatric patients with hydrocephalus continues to improve, these patients transitioning to adults require ever-increasing neurosurgical interventions. Although the transition from childhood hydrocephalus to the adult type remains poorly understood, the diversion of CSF via VP shunt placement is effective for the management of hydrocephalus in both pediatric and adult patients. However, VP shunting is associated with myriad potential complications from the shunt itself, including infection, overdrainage, mechanical obstruction, equipment failure, and disconnection. Thus, shunt system removal, replacement, or revision is inevitable in patients with hydrocephalus.[7,25]

In this study, we retrospectively evaluated 105 adult patients who underwent VP shunt placement for hydrocephalus during their pediatric years at our institution. The study primarily focused on examining the incidence of shunt revision, overall shunt survival, and risk factors associated with shunt failures in pediatric hydrocephalus patients transitioned to adults. To our knowledge, this is the first study that specifically addresses the VP shunt survival rate and the factors associated with shunt failure in these patients with hydrocephalus. However, it should be noted that the study may be subject to inherent biases because it provides a snapshot of the outcome for only 105 of the 305 patients who had initial shunt surgery during childhood (younger than 17 years) but transitioned to adulthood. Thus, the results reflect the outcomes for a subgroup of patients among 305 patients. Moreover, shunt surgeries performed at this teaching institution involve residents, attending physicians, and surgical specialists. Lund-Johansen et al[36] reported that the risk of shunt complication is generally higher in patients operated on by residents compared with those who are operated on by experienced surgical specialists. It is theoretically possible that the study results could be affected by the different criteria of different surgeons for performing shunt placement or shunt reoperation. Therefore, the findings of this investigation should be interpreted in light of its inherent limitations.

Overall, the results of this study show that the incidence of shunt revision for the entire study period was 82.9%. Although the incidence of shunt failure is not known for pediatric hydrocephalus patients transitioned to adults, previous studies suggest that the risk of shunt failure is high during the first shunt placement, and approximately 5% of failures during each subsequent year.[28,37] The results of this study are consistent with those previously published long-term studies in which a 70% to 80% shunt failure rate was seen in patients with hydrocephalus.[37-40] In addition, the 6-month shunt failure rate (15.2%) observed in this study is well in agreement with the recent findings reported by Farahmand et al[34] in which they found that 85 of the 450 patients with hydrocephalus (18.9%) experienced shunt revisions within the first 6 months after shunt placement.

To better understand the risk of shunt failure in adult-transition patients with pediatric-onset hydrocephalus, we evaluated the incidence of shunt failure history and risk factors during pediatric years (younger than 17 years) and during adult years (older than 17 years) separately. The median number of shunt revisions was higher during pediatric years (3; range, 1-15) than that during adult years (2; range, 1-9). The median time to shunt revision was shorter during pediatric years (4.1 years; range, 0-16.6 years) compared with that of adult years (21.3 years; range, 0.1-42.0 years). These results clearly suggest that shunt complications were more frequent during pediatric years compared with those occurring during adult years.

Furthermore, the results of the study show that patients with congenital hydrocephalus experienced significantly higher shunt failure rates compared with those with tumors/cysts or other etiologies. Similarly, patients with communicate hydrocephalus had significantly higher shunt failure rates compared with those with obstructive hydrocephalus. Moreover, the findings from multiple logistic regression analysis show that etiology of hydrocephalus is independently associated with shunt failure in adult-transition patients with pediatric-onset hydrocephalus. However, the impact of etiology on shunt revision was significant only during the pediatric years but was not present during the adult years.

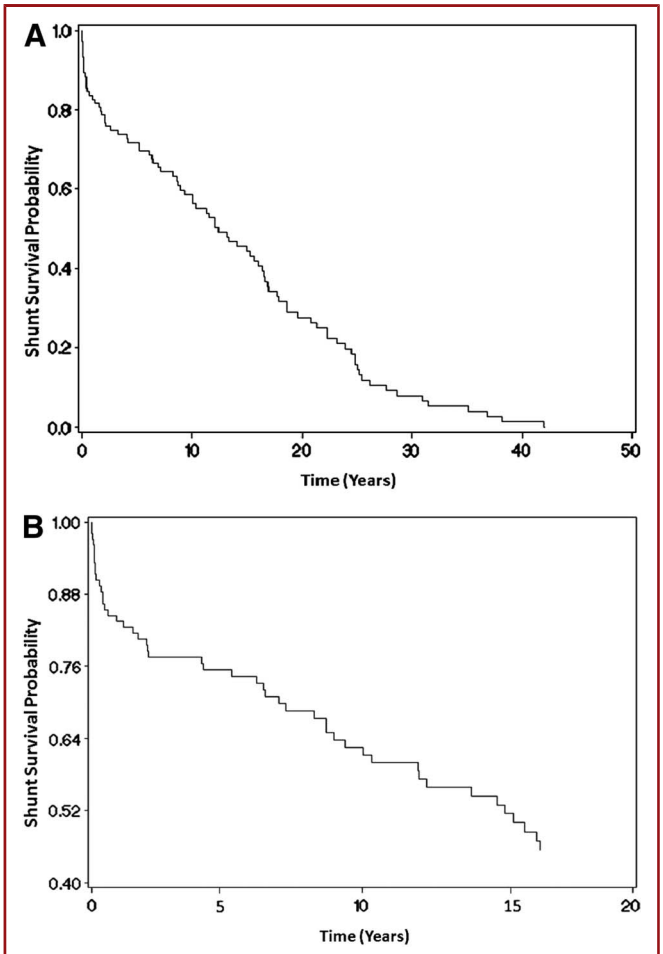

FIGURE 2. **A**, *Kaplan-Meier curve showing the overall shunt survival in adult transition patients with pediatric onset hydrocephalus.* **B**, *Kaplan-Meier curve showing the overall shunt survival in adult-transition patients who had their first shunt failure before the age of 17 years and treated with a ventriculoperitoneal shunt surgery.*

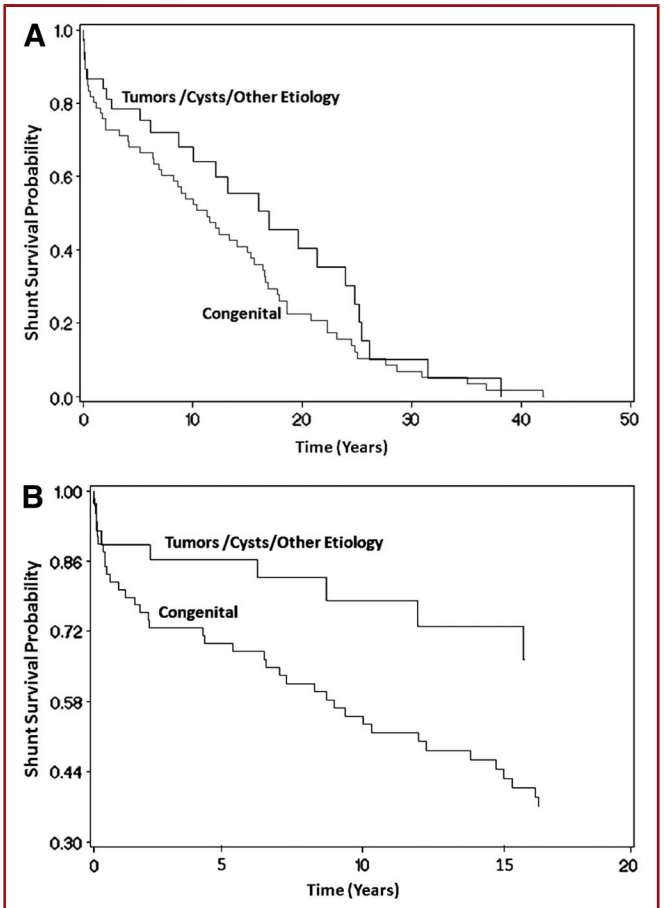

FIGURE 3. **A**, *the Kaplan-Meier curve showing the overall shunt survival according to etiology of hydrocephalus in adult-transition patients with pediatric-onset hydrocephalus. No significant differences were observed among patients with different etiologies of hydrocephalus (log-rank test,* $P > .05$*).* **B**, *Kaplan-Meier curve showing the overall shunt survival according to etiology in adult-transition patients who had their first shunt failure before the age of 17 years. The Kaplan-Meier plot demonstrates significant differences in the median time to shunt failure between the patients with congenital hydrocephalus and tumors/cysts and other etiologies of hydrocephalus (log rank test,* $P < .02$*).*

Currently, it is unclear why these differences exist in shunt failure rates among patients with different etiologies, specifically between the pediatric years and adult years. Further investigation is required to define the precise role of these variables in the management of adult transition patients with pediatric-onset hydrocephalus.

Risk factors for multiple shunt revisions were determined among the patients with at least 1 shunt revision. The findings indicate that being pediatric at first shunt revision, infection, proximal shunt complication, and other causes are independent risk factors for multiple shunt failures in adult-transition patients with pediatric-onset hydrocephalus. A thorough analysis of risk factors that are associated independently with multiple shunt failures in adult patients with pediatric-onset hydrocephalus needs further evaluation.

Infection, obstruction, and overdrainage are major causes of shunt malfunction resulting in shunt revision in adult-transition patients with pediatric-onset hydrocephalus. Many of these complications are believed to be directly related to surgical procedure and patient management. Therefore, in this study, we evaluated these major causes and other complications in relation to shunt revision in adult hydrocephalus patients. Our results show that shunt infection accounted for 11.9% of total revisions, whereas shunt obstruction and overdrainage accounted for 50.9% and 6.5% of the total revisions, respectively.

Overall, the results of this long-term analysis demonstrate that most patients who are shunt dependent experience multiple shunt failures requiring revisions. To optimize the clinical outcomes in shunt-dependent patients, several studies focused on improving shunts by developing material and valve mechanisms.[41-43] In addition, endoscopic neurosurgery such as ETV has been

developed as an alternative to avoid open surgery or shunt insertion–related adverse events. However, a quality-adjusted life-year decision analysis study by Drake et al[44] suggests that ETV is not superior to shunt surgery; the procedure seems to be somewhat counterintuitive, particularly in older pediatric age groups. Other studies also indicate that VP shunt surgery has outcomes comparable to or better than ETV as a treatment for hydrocephalus.[45-47] Nonetheless, a direct comparison of the clinical outcomes may be difficult because of differences between patients selected for ETV vs shunt surgery. This procedure allows the ventricular CSF to bypass anatomic obstructions and directly enter, and be absorbed through, the subarachnoid space via the hole created in the floor of the third ventricle, without the need for any implanted foreign device.

This study is subject to a number of important limitations. One important shortcoming of this report is the retrospective nature of the study. Although a uniform technique for VP shunt placement was used, the overall treatment was chosen by a number of neurosurgeons. Moreover, the variables included in this study could not be analyzed in a controlled way. Also, many of the variables were dependent on the decisions of individual neurosurgeons involved in the shunt placement.

CONCLUSION

The results of this study show that most adult-transition patients with pediatric-onset hydrocephalus experience multiple shunt failures requiring revisions. The etiology of hydrocephalus was shown to be an independent risk factor for shunt failure in adult-transition patients who had their first shunt failure before the age of 17 years. Being a pediatric patient at first shunt revision, infection, proximal shunt complication, and other causes of shunt revision were independently associated with multiple shunt failures. However, prospective clinical studies are warranted to elucidate the risk factors that contribute to shunt failure in adult-transition patients with pediatric-onset hydrocephalus.

Disclosure

The authors have no personal financial or institutional interest in any of the drugs, materials, or devices described in this article.

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COMMENTS

The authors present a retrospective long-term follow-up of a group of 105 adult patients from their hospital system who all underwent treatment of hydrocephalus with insertion of a ventriculoperitoneal (VP) shunt before age 17. These patients, referred to as transition patients, represent a specific subset of the adult hydrocephalus population.[1] These patients have often been feared in the neurosurgical community because of acknowledged complexity and presumed propensity to frequent shunt failure. The authors provide us with a retrospective, detail-oriented snapshot of the VP shunt outcomes for this particular group of 105 patients. They provide data, for example, concerning hydrocephalus etiology, general long-term survival data for shunt function, type of shunt failure, and frequency of shunt revisions all with significant long-term follow-up. Their data confirm that patients with a congenital etiology (compared with those with hydrocephalus secondary to tumor or cyst) are more prone to early shunt failure and more frequent shunt failure. This builds on what is already known from the pediatric hydrocephalus/shunt population regarding long-term shunt pediatric survival and will be particularly important when we can compare the transition patients with the other groups of the adult hydrocephalus population.

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As is demonstrated in this work, hydrocephalus can be a lifelong condition requiring assessment and treatment for many decades. The authors studied a group of adults from their institution who had been shunted as children and are now being cared for as adults whom they define as the transition patients. The concept of transition can mean many things. It can mean, as it does in all individuals, the transition from childhood to adulthood. In patients with chronic conditions that begin in childhood and may be treated with some effectiveness but not relieved of the underlying pathology, this means moving from 1 center of care, 1 physician or group of physicians to another center of care. More and more in the United States it means moving from the care of a pediatric neurosurgeon in a children's hospital to a general hospital and to the care of general neurosurgeons.

The American Academy of Pediatrics has defined transition of care as one of its priorities in improving the care of children and young adults. They suggested a concept they call the "Medical Home Model."[1,2,6] The concept here is that there is a geographically distinct area of care that serves both adults and children. Adult practitioners are available to provide guidance to pediatric physicians and vice versa. In such a "medical home," there is a continuous medical record and an effective tracking system. The authors from Louisiana State University Health Center–Shreveport appear from their ability to track patients from one stage of life to another to have such a model of the provision of health care. Defining the problems inherent in transition of health care is the first step to understanding the problems and beginning to deal with them. The study provided here demonstrates that the majority of patients who are shunted in childhood remain dependent on their shunts beyond the childhood years and remain at risk of shunt failure. This fact requires those treating the patients in childhood to attempt to prepare their patients for the time when they will not be available to these at-risk individuals any longer. They must be aware that they remain at risk and must be counseled as to how to access such care in adult-centered environments.

Although a clear outcome measure from a statistical point of view, the need for shunt revision does not tell the whole story of the burden that shunt dependency weighs on adults with hydrocephalus that begins in childhood. This study shows that the risk of recurrent shunt failure is related to the etiology of the hydrocephalus, being higher in patients in whom the etiology was congenital and in whom the need for treatment was in infancy. The causes of hydrocephalus in this group of individuals are distinct from acquired forms that may lead to hydrocephalus at any age such as that caused by hemorrhage, tumor, and meningitis. For one thing, a substantial number of these patients will have no ventricular dilation at the time of overt shunt failure. This seems to be the case in between 20% and 25% of cases of hydrocephalus that begin in childhood.[3,4] The second issue relates to the effect that this burden has on the lives of the adults trying to compete in the world. In a self-reporting database with all the bias that that implies, 73% of patients with shunts who are between 20 and 45 years of age had been shunted in the first year of life. In this study, the median time of the first shunt was 1 year, so these 2 parameters do not

seem too out of line. Of that group, 40% had daily disabling headaches as opposed to the international incidence of chronic daily headaches of 4%. How much of this headache problem relates to abnormal intracranial pressure disorders and how much to other factors cannot be assessed at this time, but the result that they need a large number of scans and may undergo multiple revisions of the shunt is inescapable.

The authors state that they will be delving into this patient population more thoroughly in the near future. They should be encouraged to do so. They also suggest that prospective clinical trials and studies are warranted. I completely agree, but there are great challenges because of how long the studies will have to be extended to assess important outcome measurements. The type of assessment done here with all of its limitations should be pursued more generally and possibly with a multicenter registry of such patients to assess the specific problems related to shunt dependency for decades, the specific technical issues related to long-term shunt dependency, and finally the effects of shunt dependency on adults shunted in infancy. The important questions that remain are should we be doing something different in infancy to improve the outcome for adults and what can we do to ensure that adult patients who leave pediatric-oriented care settings will get appropriate care for complicated problems of hydrocephalus?

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