



ETV/CPC and Ventriculoperitoneal Shunt Outcomes by a Pediatric General Surgeon in Tanzania: A Case for Task-Shifting to Meet Global Neurosurgical Need?

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Scholarly Report submitted in partial fulfillment of the MD Degree at Harvard Medical School

Date: 01 March 2018

Student Name: Andrew Ikhyun Kim, MPhil

Scholarly Report Title:

Part 1: Characterization of Hydrocephalus and its Neurosurgical Interventions in Arusha, Tanzania

Part 2: ETV/CPC and Ventriculoperitoneal Shunt Outcomes by a Pediatric General Surgeon in

Tanzania: a Case for Task-shifting to Meet Global Neurosurgical Need?

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Section 1: Abstract

Object: In low- and middle-income countries, hydrocephalus is one of the most common congenital birth defects. Traditionally, shunt placement has been the major intervention for hydrocephalus. More recently, Endoscopic Third Ventriculostomy with Choroid Plexus Cauterization (ETV/CPC) was introduced as a low-cost, effective alternative. This study seeks to characterize hydrocephalus and its neurosurgical outcomes in Tanzania and to assess the feasibility of training a pediatric general surgeon in performing ETV/CPC.

Methods: Part 1 of this combined prospective/retrospective cohort study characterizes hydrocephalus and its treatment in Arusha, Tanzania. Measured variables include etiologies of hydrocephalus, ages and demographics at treatment, severity of disease, numbers of patients, 30-day morbidity and mortality of shunt placement, and rates of shunt failure/infection (based on Kaplan-Meier method).

In part 2 of this study, a pediatric general surgeon from Tanzania was provided with ETV/CPC training. We allowed a 3-month latency period for her to become familiarized with the procedure. Then, we prospectively collected data from a consecutive cohort of 9 months of patients with hydrocephalus. Our main variables of interest were failure rate, failure reason, and 30-day mortality. We used the Kaplan-Meier method to determine if there was a significant difference in neurosurgical outcomes for hydrocephalus between VPS and ETV.

Results:

Part 1: Of 136 patients studied, average age of hydrocephalus onset was 2.98 months, average age of first illness was 1.81 months, and average age at treatment was 11.22 months. The most common etiologies were myelomeningocele (32 percent), congenital idiopathic (30 percent), post-infectious (26 percent), and encephalocele (4 percent). Overall, the VPS failure rate was 39.2 percent with an average time to failure of 8.18 months and average number of failures as 1.84. Most common reasons for failure included shunt malfunction (78 percent), shunt infection (16 percent), and wound dehiscence (6 percent). The 30-day mortality rate was 3.1 percent. Kaplan-Meier analyses showed no significant survival or VPS failure differences based on identified patient characteristics.

Part 2: Of 32 patients evaluated for ETV, 23 ETV surgeries were attempted and 17 (73.9 percent) were successful. 6 were converted to VPS for reasons of technical issues (33.3 percent), scarred third ventricle floor (33.3 percent), and poor visualization (33.3 percent). The etiologies of hydrocephalus were 38 percent PIH and 62 percent NPIH. After a median follow-up of 57 days, the VPS failure rate was 37.5 percent and ETV failure rate was 5.9 percent ($p=0.3192$). The direction of revisions were as follows: prior VPS to new VPS ($n=2$), prior VPS to new ETV ($n=1$), and prior ETV to new VPS ($n=1$). There were no deaths during our follow-up period. Kaplan-Meier analyses showed no significant survival or VPS failure differences based on patient characteristics or surgery. There was a significantly shorter treatment delay in part 2 compared to part 1 (0.31 vs. 8.2 months, $p= 0.0276$).

Conclusion: Overall, these analyses in Tanzania show that (1) etiologies of hydrocephalus are evenly split between myelomeningocele, congenital idiopathic, and post-infectious, (2) neurosurgical outcomes based on shunt placement showed high shunt failure rates within one year, most commonly due to shunt malfunction, and (3) early outcomes of ETV by a pediatric general surgeon were not significantly different from VPS outcomes, with results limited by small sample size. A determination of equivalence or superiority between these surgical approaches by a pediatric general surgeon requires further research.

Section 2: Student role

I conducted the entirety of the research, with advice and guidance from my mentors. My roles included forming relationships at each hospital (ALMC and CCHU), acquiring data from hospital records, analyzing CT scans, organizing data, inquiring about clarifications or missing data from data clerks and nurses at the hospitals, analyzing the data, and presenting and writing up the findings. I also liaised with the teams at ALMC and CCHU to help coordinate the training of Dr. Catherine Mung'ong'o in ETV/CPC and in setting up the data collection system.

I shadowed, observed, and conversed with neurosurgeons to understand the shunting and ETV/CPC procedures. I learned the FOR method for head circumference and ventricle size measurement from Dr. Ben Warf in April and May of 2014 before departure. Moreover, I was responsible for maintenance of the ALMC database, with the help of the CCHU IT team.

This was done over a period of 3 months in-country time in Uganda and Tanzania between 2014-2017, working 40 hours per week during those times.

I also returned to Tanzania in December 2017 to work full-time for 1 month in collecting and analyzing post-intervention data. I also conducted semi-structured interviews with the neurology nurse to fill in gaps in data and gain perspectives on outcomes not charted in the medical records.

The preliminary results were presented at the Annual Soma Weiss Research Symposium and at the Klingenstein Fellowship Annual Poster Session in 2015. At the time of SIM report submission, we are editing the manuscript for submission for publication.

Other contributors' roles are outlined below:

Benjamin Warf: Principal investigator who provided all research guidance.

Mark Jacobson: Coordinated all logistics from the side of ALMC. Provided permission for the study and introductions for all collaborators at ALMC.

Catherine Mung'ong'o: Pediatric surgeon who performed more than 95% of the surgeries analyzed in the study. Also attended two ETV/CPC trainings in Mbale, Uganda and initiated these surgeries.

Golda Orega: Neurosurgery nurse who documented all patient records into the electronic data-collection system that we set up.

Charles Howard: Coordinated all logistics from the side of CURE Children's Hospital of Uganda.

Collins Kabachelor: Helped with information technology and surgical equipment set-up.

Section 3: Acknowledgements

I would like to express my gratitude to:

Ben Warf, Charles Howard, Kerrilee Killea, and Collins Kabachelor at CCHU for providing all logistical support in this project including providing free ETV/CPC training for Dr. Catherine Mung'ong'o and for providing the equipment and data collection systems required to implement our study.

Mark Jacobson, Catherine Mung'ong'o, and Golda Orega at ALMC for hosting our study at their institution and for conducting the surgeries and medical records keeping required for the success of this study.

Kari Hannibal, Marcie Neumowicz, Kerenne Paul, and the Scholars in Medicine Office for their financial, logistical, and emotional support.

Finally, I am most grateful to my parents, John Hyungjoon Kim and Yong Eun Park, and to my steadfast partner, Katherine Jacobson, for their emotional and mental support throughout this time.

Appendix—Manuscript in Format for Journal of Neurosurgery: Pediatrics

Title: Hydrocephalus and its Neurosurgical Outcomes by Pediatric General Surgery in Tanzania

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Introduction:

The global burden of hydrocephalus is variable but significant. In sub-Saharan Africa (SSA) alone, the incidence of hydrocephalus is 100,000 to 375,000 cases annually.¹¹ Traditionally, ventriculoperitoneal shunt (VPS) placement has been the major intervention for hydrocephalus. However, shunts require significant maintenance and are associated with complications such as failure and infections. More recently, Endoscopic Third Ventriculostomy with Choroid Plexus Cauterization (ETV/CPC) was introduced as a low-cost, effective alternative.⁸ Studies in Uganda have shown the effectiveness of ETV/CPC. However, data on the global burden of hydrocephalus and ETV/CPC remains limited and locally specific.

Moreover, given the relative dearth of neurosurgeons in most low- and middle-income countries, task-shifting has become an enticing option to meet neurosurgical need.^{2,3,5} No prior studies have demonstrated the feasibility of training a pediatric general surgeon in ETV/CPC to meet neurosurgical need for hydrocephalus.

This study has two parts with two main objectives. Part 1 of this study aims to expand upon the limited information on hydrocephalus in sub-Saharan Africa through addition of data from Tanzania. It documents the burden and etiologies of hydrocephalus, along with its conventional neurosurgical outcomes. Part 2 of this study analyzes the surgical outcome of VPS vs. ETV by a pediatric general surgeon after training in ETV/CPC.

Materials and Methods/Case Material:

We conducted a prospective and retrospective analysis of surgical outcome data on all children treated for hydrocephalus via ETV/CPC or shunting in Arusha Lutheran Medical Center, Tanzania. The time frame for patient data in part 1 was neurosurgical intervention from 2014-2015. Inclusion criteria were infants <1 year at onset of hydrocephalus, history of febrile illness and/or seizures preceding hydrocephalus onset or endoscopic/imaging findings indicating prior ventriculitis (scarring, loculation, thickened ependyma, etc.), congenital hydrocephalus as defined in clinical record at diagnosis. Exclusion criteria were Dandy-Walker Malformation and loss to follow-up immediately after surgical intervention.

Variables collected included etiologies of hydrocephalus, ages and demographics at treatment, severity of disease (approximated by head circumference), numbers of patients; 30-day operative mortality; rates of shunt failure defined by obstruction (using the Kaplan-Meier method); shunt infection (Kaplan-Meier method); percent lost to follow-up; and follow-up duration. Classification of post-infectious hydrocephalus (PIH) and non-post infectious hydrocephalus (NPIH) were made by definitions laid out in Figure 1.

We used an adaptation of standard treatment success criteria: a deceleration in head circumference growth to a normal or lower rate; decompression of the anterior fontanel; relief from

symptoms of elevated intracranial pressure; and/or resolution of abnormal eye findings. Treatment failure was defined as need for repeat surgery for hydrocephalus.

We collaborated with the Cure Children's Hospital of Uganda (CCHU) IT team to set up a CCHU-analogous database with remote access for data collection. Follow-up was conducted by in-country staff at 30 days, 3 months, and 6 months, or when patients presented to clinic with complaints.

In part 2, a Tanzanian pediatric general surgeon underwent two trainings for ETV/CPC in CCHU in Mbale, Uganda. After the ETV/CPC training, we allowed for a latency period of 3 months to allow for her to achieve baseline comfort with the procedure. Then, we allowed for 9 months of patient data collection for the new ETV/CPC procedure in Arusha, Tanzania. We collected the same variables and conducted the same analysis as in part 1 of the study. P values were calculated using two-tailed t-tests for continuous variables and Fisher's exact test for categorical variables. Kaplan-Meier survival curves were conducted, comparing ETV vs. VPS outcomes in part 2. All statistical analysis was done in GraphPad, R, Excel, and Eureka statistics.

Approval received from the institutional review boards (IRBs) at both Harvard and Arusha Lutheran Medical Center for collection and analysis of data from human subjects.

Results:

Part 1:

A total of 173 patients were found in the hydrocephalus and spina bifida program at ALMC during 2014-2015 (Figure 2). After excluding 14 patients with incomplete charts, we analyzed data from 159 patients. Of these, 23 were excluded as they had spina bifida without manifestations of hydrocephalus; 5 patients with hydrocephalus were excluded because they were lost to follow-up before their scheduled VPS date; and 15 were excluded from the surgical outcomes analysis only as they were lost to follow-up immediately after discharge from surgery. One patient was excluded during data analysis for inconsistencies in data.

Patient Characteristics

Of the 130 patients included in the study, 58.1 percent were male and 48.9 percent female. The average age of the at first related illness was 1.8 months old and diagnosis of hydrocephalus was 3.0 months old. The average age of treatment was 11. 2 months old. The median onset of illness and diagnosis were before the 1st month of life, and the median age at treatment was 5 months. The most common presenting illnesses were increasing head size, eye changes, fever, seizures, and vomiting. These and other pertinent patient demographics are compiled in Table 1.

Etiologies of Hydrocephalus and Associated Conditions

The most common etiologies of hydrocephalus were myelomeningocele (32 percent), congenital idiopathic (30 percent), post-infectious (26 percent), and encephalocele (4 percent) (Table 2). Using our pre-determined classifications of PIH and NPIH, the etiologies were split 26 percent PIH and 74 percent NPIH.

The most common associated symptoms and conditions included spina bifida (32.4 percent) and clubfoot (5.15 percent). Of the 32.4 percent with preceding or concurrent spina bifida, the distribution was 12 percent encephalocele, 40 percent lumbar, 13 percent lumbosacral, 13 percent sacral, and 22 percent other, which included undefined or multiple locations (Figure 3).

VPS Outcomes

Overall, after a median follow-up time of 2.8 months, the VPS failure rate was 39.2 percent with an average time to failure of 8.18 months (median 1.75 months). Amongst those with any failures, the average number of failures as 1.84. The maximum number of failures was 12. Most common reasons for failure included shunt malfunction (78 percent), shunt infection (16 percent), and wound dehiscence (6 percent). The 30-day mortality rate was 3.1 percent. (Table 3).

The average age at treatment was 11.22 months with 80 percent receiving surgery before 12 months of age. The average delay between illness-to-treatment and diagnosis-to-treatment were 9.4 and 8.2 months, respectively; whereas the median delay for both illness-to-treatment and diagnosis-to-treatment was 5 months. From interviews with the neurosurgery nurse and from chart review, the most common reasons for delay were challenges in scheduling, transport, and ability to pay.

The results of the Kaplan-Meier analysis stratified by (1) age at treatment less than or equal to 12 months versus greater than 12 months, and (2) etiology of hydrocephalus as PIH versus NPIH are shown in Figure 4. KM curves for composite all-cause mortality, hydrocephalus related mortality, and shunt failure showed no significant differences between age at treatment or etiology of hydrocephalus (95% CI overlapping, Figure 4).

Part 2: Post-ETV Training

A total of 32 patients with hydrocephalus were evaluated for potential ETV during our 9-month timeframe and 23 ETVs were attempted. One patient was excluded due to loss to follow-up prior to surgery. Due to technical issues, the study center had inconsistent capability to perform CPC and thus performed only ETV. Of the 23 ETV attempts, 73.9 percent were successful. 6 were converted to VPS for reasons of technical issues (33.3 percent), scarred third ventricle floor (33.3 percent), and poor visualization (33.3 percent).

Patient characteristics for this new sample of 31 patients was overall similar. 64.5 percent were male and 35.5 percent were female. The etiologies of hydrocephalus were 38 percent PIH and 62 percent

NPIH (48 percent congenital idiopathic, 6 percent arrested, 3 percent post-hemorrhagic, and 3 percent unknown). The results are tabulated alongside demographics for part 1 in Table 1.

After a median follow-up of 57 days, the VPS failure rate was 37.5 percent and ETV failure rate was 5.9 percent ($p=0.3192$ by Fisher's Exact Test). The only significant difference between the ETV vs. VPS groups were unsuccessful surgery attempts (6 in ETV and 0 in VPS, p value 0.0192). Amongst the failures, the reasons for revision were evenly split between overdrainage ($n=1$), CSF leak ($n=1$), shunt infection ($n=1$), and poor flow ($n=1$). The directions of revisions were as follows: prior VPS to new VPS ($n=2$), prior VPS to new ETV ($n=1$), and prior ETV to new VPS ($n=1$). There were no deaths during our follow-up period. In comparing the results from part 1 to part 2, the age of onset of hydrocephalus and age at treatment, were not significantly different (onset: 2.98 vs. 4.13 months, $p=0.5309$; treatment: 11.22 vs. 17.7 months, $p=0.3709$). However, the difference in treatment delay between the two groups was significant with less delay in part 2 (8.2 vs. 0.31 months, $p=0.0276$). Results are summarized in Table 4.

Kaplan-Meier analyses of part 2 are shown in Figure 4, comparing ETV versus VPS. The curves for stratification by age and etiology were excluded as all failures occurred in the <12 age group and the NPIH group. The 95 percent confidence intervals overlap for all analyses with no significant between-group differences in survival and surgical failure during our follow-up period.

Discussion:

Characteristics and Etiologies of Hydrocephalus in Tanzania

In contrast to prior studies from Uganda and India, which showed that approximately 60 percent of hydrocephalus cases were post-infectious in etiology,⁸ the analysis of etiologies in Tanzania in part 1 and part 2 of our study showed PIH rates of 26 percent and 38 percent, respectively. Although the sample size is smaller, the latter rate of PIH in part 2 may be more accurate given the use of endoscopic visualization as an adjunctive diagnostic tool for evidence of infection. Overall, the lower rates may be explained by differences in patient population and exposure to perinatal infection, differences in clinical diagnostic tendencies, and/or relatively higher rates of congenital spinal cord disorders due to differences in prenatal nutrition (i.e. folic acid supplementation). The likelihood of prenatal nutrition as a cause is supported by the relatively high rates of associated spina bifida (32.4 percent).

VPS Outcomes

The rates of shunt failure in our analysis (39.2 percent) were on the higher end of the range compared to prior studies from other countries. Cumulative VPS failure rates from studies in Switzerland, California, and Kenya were 42 percent, 32 percent, and 20 percent respectively.¹¹ The most common reasons for failure of shunt malfunction (78 percent), shunt infection (16 percent), and wound dehiscence (6 percent). Compared to other studies where shunt infection rates range

from 11 to 17 percent, the shunt infection rate was within a comparable range. Moreover, amongst those with failures, two patients had a comparably higher number of repeat failures (12 and 7 failures, compared to a median of 1), which may have skewed the mean number of failures higher.

Given the variable follow-up rates, median 2.8 months and mean 11.4 months, we may have missed rates of late failure. There was a high degree of right skew given patients who had returned months or even years after their initial VPS for revision. Prior studies have shown relatively high rates of late complications (12.5 percent requiring revisions 10 years or more after their VPS placement).⁶ Therefore, we must account for the fact that short follow-up time may underestimate the true complication rate for our patients, especially those lost to follow-up.

With regard to mortality, a large portion of the 13.8 percent rate of all-cause mortality during follow-up may be less useful than the 3.1 percent 30-day mortality. Where cause of death was ascertained, many died of unrelated causes such as malaria.

ETV Results

After training and acclimation to endoscopic surgery, we had a smaller-than-expected sample size for intended ETV cases in our pre-set 9-month window. Furthermore, due to technical issues, CPC was not performed on the majority of cases. Analysis from prior studies show a significantly better outcome for combined ETV-CPC (81.9 percent) than for ETV alone (48.6 percent) as treatment for hydrocephalus.⁷ Therefore, results from our ETV trial may underestimate the potential benefit of training in ETV/CPC for the treatment of hydrocephalus.

The results showed a non-significant difference failure rates for ETV (5.9 percent) compared to VPS (37.5 percent) after a median follow up of 57 days and mean follow up of 95 days ($p = 0.3192$). There was no notable difference in the direction of revision (VPS to ETV versus ETV to VPS), nor a predominant reason for failure. One possible explanation for higher VPS failure may be selection bias—if the unsuccessful ETV attempts converted to VPS reflect higher severity of disease or more difficult cases, then this may inflate the VPS failure rate. However, a further analysis of VPS failure shows that only one of the failures arose from an unsuccessful ETV case. Additionally, the VPS failure rate in part 2 is similar to that in part 1 (39.2 percent), corroborating the reliability of this rate.

However, several inconsistencies exist between part 1 and part 2 of this study. There was a significant difference between the two groups in treatment delay as defined by time from diagnosis to surgery (8.2 vs. 0.31 months, $p = 0.0276$), even after removing two outliers of children who developed hydrocephalus after age 8. The hydrocephalus and spina bifida program did not undergo any significant changes in staffing or funding between the two analyses. These were two unfiltered populations of consecutive patients at a single medical center serving a relatively stable catchment area. Given the smaller-than-expected sample size of part 2, this may be due to a deviation from the true mean. Other explanations may include interval improvements in surgical scheduling or removal of demand-side cost barriers due to the availability of ETV.

Hydrocephalus Treatment by Pediatric Surgery: A Case for Task-Shifting?

The extreme human resource deficit in neurosurgery has been highlighted repeatedly in the literature, with most recent estimates for East Africa showing a ratio of one neurosurgeon per 10 million inhabitants.² Yet, the rate of current training is insufficient to meet neurosurgical need in this region in the near future. Therefore, task-shifting to general surgeons has been proposed as a potential strategy to meet surgical need for conditions such as hydrocephalus.

This study was the first of its type to compare neurosurgical outcomes by a pediatric general surgeon before and after training in ETV/CPC. Unfortunately, given the smaller-than-expected sample size, the study was insufficiently powered to provide comparisons of non-inferiority between ETV vs. VPS by a pediatric general surgeon. Further follow-up on this study through ongoing data collection may shed light on longer-term outcomes.

Limitations

We must acknowledge multiple limitations in our study.

First, resource limitations precluded us from conducting ultrasounds, MRIs, and CSF analysis for our patients, as is done in other settings with more resources. This may have affected our ability to detect subtle differences in treatment success and subtle cases of PIH.

Second, the follow-up times for patients were relatively short in part 2 of the study (median follow-up of only 57 days). Most ETV failures occur in the 3-6 month range, and given our short follow-up, we may not have detected the full extent of failures. Subsequent analysis from long-term follow-up data may help shed light on the true ETV failure rate.

Third, the lack of CPC skews our results in part 2. A subsequent analysis of outcomes after the resolution of cauterizer issues may reflect more accurately upon the possible benefit of training a general surgeon in ETV/CPC.

Finally, this is a study of a single center and pediatric general surgeon, which may not be completely generalizable to other resource-limited settings. The overall concept, however, may be useful for many centers: a short-term training for a general surgeon in ETV/CPC to meet neurosurgical need where other solutions are not feasible.

Conclusions:

Overall, these analyses in Tanzania show that (1) etiologies of hydrocephalus are evenly split between myelomeningocele, congenital idiopathic, and post-infectious, (2) neurosurgical outcomes based on shunt placement showed high shunt failure rates within one year, most commonly due to shunt malfunction, and (3) early outcomes of ETV by a pediatric general surgeon were not

significantly different from VPS outcomes, with results limited by small sample size. A determination of equivalence or superiority between these surgical approaches and by what kind of surgeon requires further research.

Disclosures:

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No perceived conflicts of interest.

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Charles Howard, CURE Children's Hospital of Uganda

Collins Kabachelor, CURE Children's Hospital of Uganda

References

1. de Ribaupierre S, Rilliet B, Vernet O, Regli L, Villemure JG. Third ventriculostomy vs ventriculoperitoneal shunt in pediatric obstructive hydrocephalus: Results from a Swiss series and literature review. *Child's Nerv Syst.* 2007;23(5):527-533. doi:10.1007/s00381-006-0283-4.
2. Fuller A, Tran T, Muhumuza M, Haglund MM. Building neurosurgical capacity in low and middle income countries. *eNeurologicalSci.* 2016;3(NOVEMBER):1-6. doi:10.1016/j.ensci.2015.10.003.
3. Gasco J, Barber SM, McCutcheon IE, Black PM. Neurosurgery certification in member societies of the WFNS: Global overview. *World Neurosurg.* 2011;76(3-4):231-238. doi:10.1016/j.wneu.2010.10.036.
4. Gathura E, Poenaru D, Bransford R, Albright AL. Outcomes of ventriculoperitoneal shunt insertion in Sub-Saharan Africa. *J Neurosurg Pediatr.* 2010;6(4):329-335. doi:10.3171/2010.7.PEDS09543.
5. Khamlichi AEL. Chapter 26 Neurosurgery In Africa. (1).
6. Stone JJ, Walker CT, Jacobson M, Phillips V, Silberstein HJ. Revision rate of pediatric ventriculoperitoneal shunts after 15 years. *J Neurosurg Pediatr.* 2013;11(1):15-19. doi:10.3171/2012.9.PEDS1298.
7. Warf BC. Comparison of endoscopic third ventriculostomy alone and combined with choroid plexus cauterization in infants younger than 1 year of age: a prospective study in 550 African children. *J Neurosurg.* 2005;103(6 Suppl):475-481. doi:10.3171/ped.2005.103.6.0475.

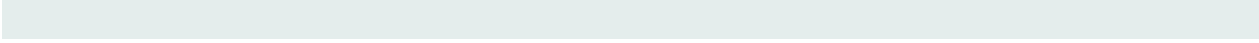
8. Warf BC. Hydrocephalus in Uganda: the predominance of infectious origin and primary management with endoscopic third ventriculostomy. *J Neurosurg.* 2005;102(1 Suppl):1-15. doi:10.3171/ped.2005.102.1.0001.
 9. Warf BC. Hydrocephalus associated with neural tube defects: Characteristics, management, and outcome in sub-Saharan Africa. *Child's Nerv Syst.* 2011;27(10):1589-1594. doi:10.1007/s00381-011-1484-z.
 10. Warf, Benjamin. "Hydrocephalus: Tackling a Global Health Problem." Vector. Boston Children's Hospital, 9 Aug. 2011
 11. Wu Y. Ventriculoperitoneal Shunt Complications in California : 1990 To 2000. *Neurosurgery.* 2007;61(3):557-563. doi:10.1227/01.NEU.0000280021.61888.C8.
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Figure Legend:

Figure 1: Algorithm for distinguishing PIH versus NPIH

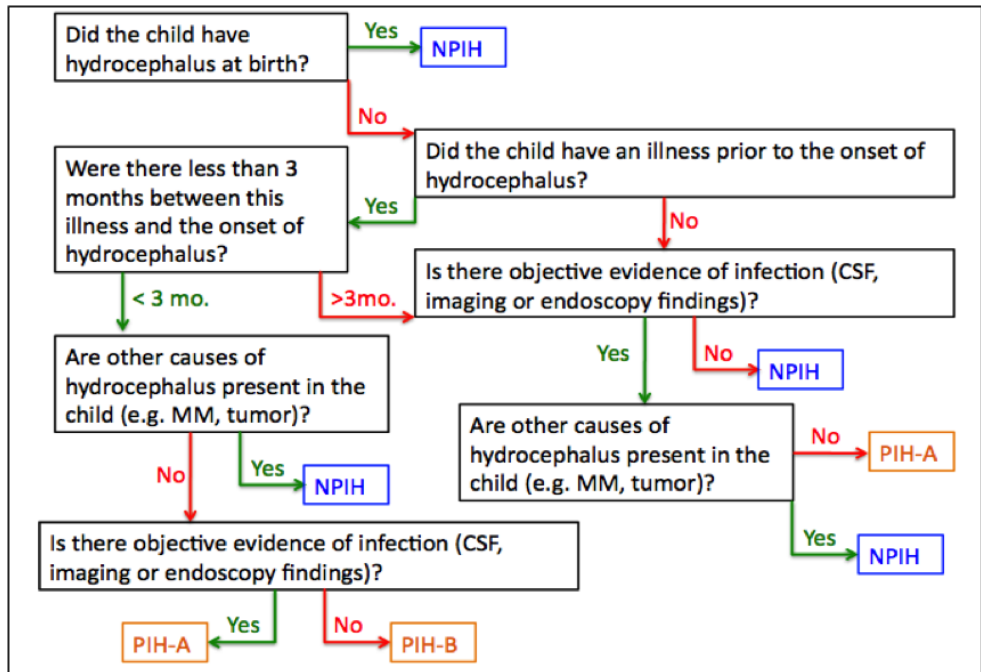


Figure 2: Patient Inclusion and Exclusion

136 patients for hydrocephalus were analyzed for characteristics data analysis. 131 patients with VPS surgeries were analyzed for VPS outcomes data. 116 surgeries with follow-up were included in Kaplan-Meier analysis.

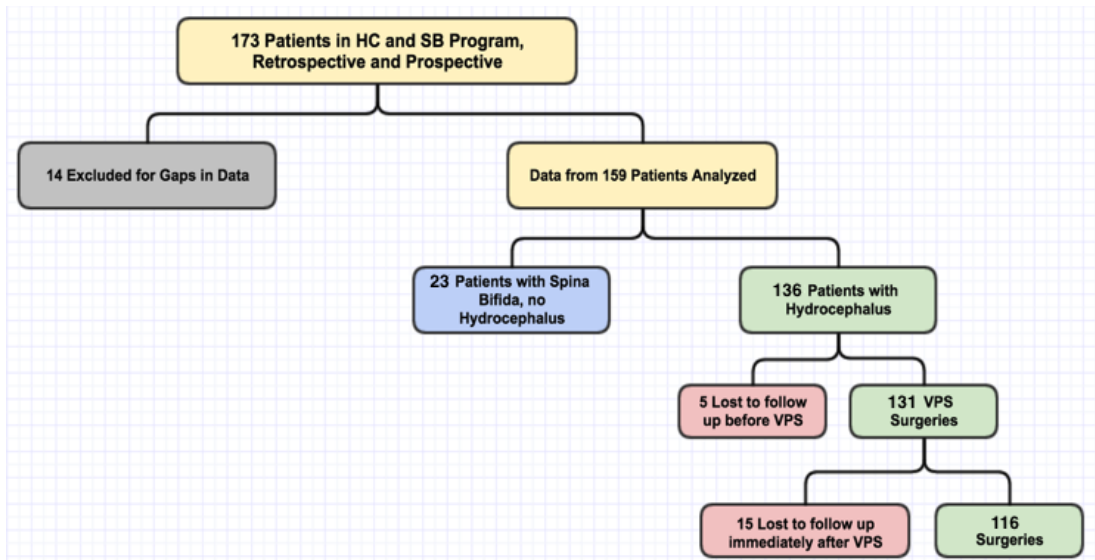


Figure 3: Locations of Spina Bifida Associated with Hydrocephalus

From data from part 1, characterization study. Abbreviations as follows: EE = Encephalocele, L = Lumbar, S = Sacral, LS = Lumbosacral. Other includes those with multiple locations and those with locations unspecified after chart review and neurosurgery nurse interview.

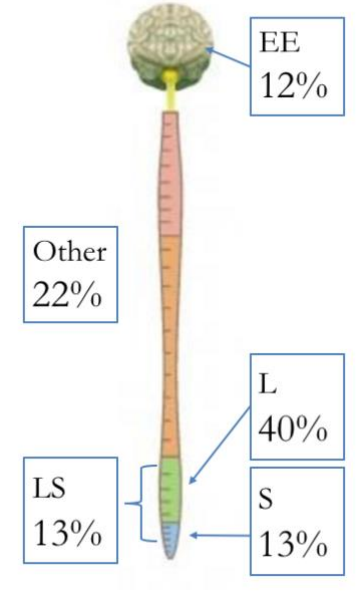


Figure 4: Kaplan Meier Curves for Ventriculoperitoneal Shunts

Kaplan-Meier survival analyses for 40-month post-operative death and VPS failure with 95% CI (shaded regions). Time (x-axis) in months. a) composite deaths. b) stratified by age at surgery > 12 months, ≤ 12 months. c) stratified by PIH, NPIH. d) composite failure. e) stratified by age at surgery > 12 months, ≤ 12 months. f) stratified by PIH, NPIH

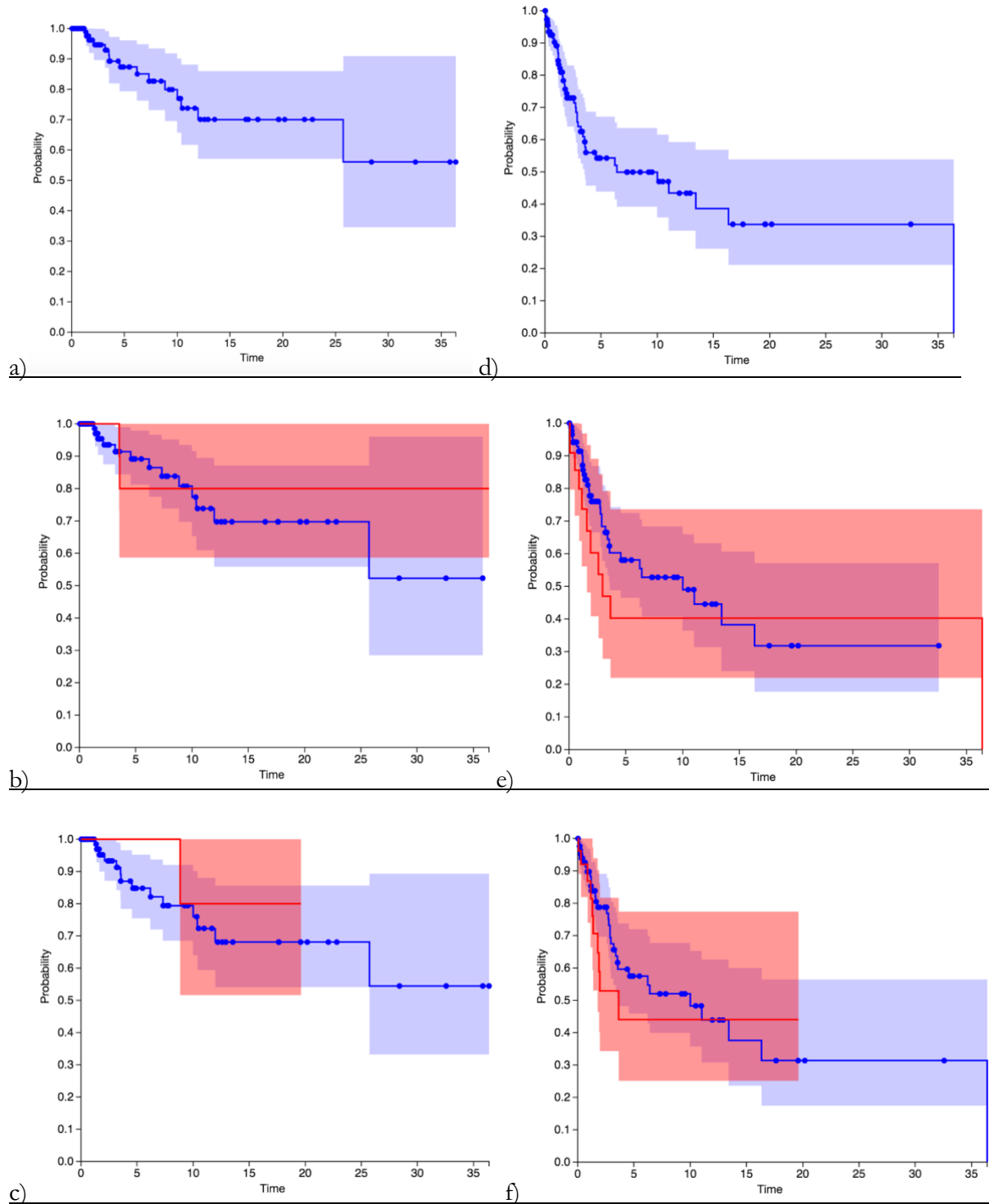
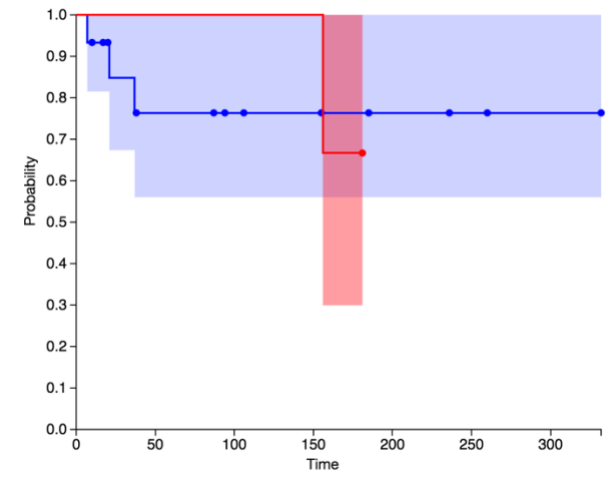


Figure 5: Kaplan Meier Curves for Endoscopic Third Ventriculoscopy

Kaplan-Meier survival analysis for post-operative surgical failure with 95% CI (shaded regions) comparing composite failure between ETV vs. CPC. Time (x-axis) in days. Graphs for stratification by etiology of hydrocephalus (NPIH, PIH) and age at treatment (> 12 months, ≤ 12 months) not shown as all failures were in NPIH and ≤ 12 month groups, respectively.



Tables:

Table 1: Patient demographics and Characteristics

Data are no. (%) of patients, unless otherwise indicated. In part 2, two outliers with high age at onset, diagnosis and treatment >8 years old skewed the data. The numbers with outlier inclusion (exclusion) are both included.

	Part 1 Patients	Part 2 Patients
Total number	136	32
Gender		
Male	79 (58.1)	20 (64.5)
Female	57 (41.9)	11 (35.5)
Age at illness	1.8 months	9.78 months (4.13 months with outlier exclusion)
Age at diagnosis	3.0 months	17.38 months (9.03 months with outlier exclusion)
Age at treatment	11.2 months	17.7 months (9.95 months with outlier exclusion)
Follow up (Mean and Median)	11.4 months, 2.8 months	2.8 months, 1.9 months
Surgical intervention	131	32
VPS	131	15
ETV	0	17
Associated conditions		
Spina Bifida	44 (32.4)	4 (12.5)
Clubfoot	7 (5.15)	0 (0)

Table 2: Etiologies of Hydrocephalus

Etiology	% of Patients
PIH	26%
MM	32%
CIH	30%
Cyst	1%
EC	4%
AS	2%
PHH	1%
Unknown	1%

Table 3: VPS Surgical Outcomes

Data are no. (%) of patients, unless otherwise indicated. One patient excluded for gaps in data for n = 130.

Average Age at Surgery		11.22 months
	≤ 12 months	104 (80)
	> 12 months	26 (20)
Failure Rate		64 (39.2)
Average Number of Failures		1.84
Average Time to Failure		8.18 months
Reasons for Failure		
	Shunt Malfunction	101 (78)
	Shunt Infection	21 (16)
	Wound Dehiscence	8 (6)
30-day Mortality Rate		4 (3.1)
All-cause Mortality Rate during Follow-up		17 (13.1)

Table 4: ETV vs. VPS Surgical Outcomes

Data are no. (%) of patients, unless otherwise indicated. Asterix (*) indicates p values that meet pre-defined significance level of $p \leq 0.05$.

Characteristic		ETV (n=17)	VPS (n=15)	P value
Average Age at Surgery		13.1 months	23.2 months	0.4001
Unsuccessful attempts		6 (35.3)	0 (0)	0.0192*
Failures		1 (5.9)	3 (37.5)	0.3192
Average Time to Failure		5.2 months	0.72 months	n/a
Reasons for Failure				
	Shunt Malfunction		1	n/a
	Shunt Infection		1	n/a
	Obstruction	1		n/a
	Overdrainage		1	n/a
Revision Direction				n/a
	To VPS	1	1	n/a
	To ETV		1	n/a
	To EVD		1	n/a
30-day Mortality Rate		0 (0)	0 (0)	n/a
All-cause Mortality Rate during Follow-up		0 (0)	0 (0)	n/a