Trends in the Treatment of Pediatric Hydrocephalus Since 2014: Understanding the Role of the 2014 Hydrocephalus Guidelines

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BACKGROUND AND OBJECTIVES: The management of hydrocephalus has significantly changed over the past decade. Endoscopic third ventriculostomy has become more prevalent, and shunt surgery has become more protocolized through research efforts by the Hydrocephalus Clinical Research Network. In 2014, the Pediatric Hydrocephalus Guidelines were first published, providing a cohesive source for clinical guidance. We planned to investigate national trends in the management of pediatric hydrocephalus after the publication of the 2014 Pediatric Hydrocephalus Guidelines as guidelines act as a compilation of historic and recent literature in a scientific field.

METHODS: A multipronged approach was used to evaluate changes in the treatment of pediatric hydrocephalus since 2014. First, we queried the Pediatric Health Information System between 2013 and 2018 to identify national trends in shunt procedures for hydrocephalus. To assess the recommendation in the guidelines to use antibiotic-impregnated catheters (AICs) in shunts, national sales records of AICs were obtained from 2 large neurosurgical device companies.

RESULTS: A total of 11,179 shunt procedures were performed within the Pediatric Health Information System database in the study period. In the preguideline publication period (2013-2014), there was a shunt revision-to-placement ratio of 1.63 while in the postguideline publication period (2015-2018), there was a ratio of 0.84 ($P < .0001$). National sales data revealed that antibiotic-impregnated drain sales increased from 2% to 77% since publication.

CONCLUSION: Findings from this investigation suggest progress in pediatric hydrocephalus management since 2014. The shunt revision-to-placement ratio improved, and the use of AICs increased over this period. Improved outcomes are likely associative findings rather than causative with the guidelines representing a culmination of widespread changes in hydrocephalus care such as increased use of endoscopic third ventriculostomies, protocolized care, and image-guided shunt placement. Further research into the impact of clinical practice guidelines is needed to better understand the impact of this tool on surgeons and patient care.

KEY WORDS: Hydrocephalus, Database, Guidelines, Quality, Shunt

Hydrocephalus is a common neurological disorder, with a prevalence of 88/100 000 in children and 11/1 000 000 in adults.[1] Ventricular shunt placement, one of the most common procedures performed by pediatric neurosurgeons, is often used to treat hydrocephalus.[2] Management of hydrocephalus has significantly changed over the past 2 decades with the adoption of endoscopic third ventriculostomy with or without choroid plexus cauterization and the invention of antibiotic-impregnated shunt components.[3-5] In addition, hydrocephalus care and research in North America has shifted toward evidence-based medicine and protocolization with the formation of the Hydrocephalus Clinical Research Network (HCRN) in 2006.[6]

An evidence-based, systematic compilation and interpretation of the literature on hydrocephalus was published in November 2014 and updated in 2020 as the Congress of Neurological Surgeons (CNS) Guidelines on Pediatric Hydrocephalus.[7,8]

ABBREVIATIONS: AIC, antibiotic-impregnated catheter; **CNS,** Congress of Neurological Surgeons; **HCRN,** Hydrocephalus Clinical Research Network; **ICD,** International Classification of Disease; **PHIS,** Pediatric Health Information System.

These guidelines covered multiple topics including posthemorrhagic hydrocephalus management, the utility of operative adjuncts such as navigation, ultrasound, endoscopy, the management of shunt infections, and the use of different valve and catheter types. Overall, the level of evidence was low for most of the recommendations. A higher level of evidence was available to support recommendations on the treatment of neonatal hydrocephalus in premature infants with posthemorrhagic hydrocephalus and to support recommendations on the use of antibiotic-impregnated catheters (AICs).[8-10] AICs were found to have a lower risk of shunt infection compared with conventional catheters, and shunt valve type was found to have no effect on shunt malfunction. Since being published, the impact of the guidelines on the treatment of hydrocephalus has not been evaluated.[11,12] The purpose of this study was to assess how hydrocephalus care has changed in the past decade after the publication of the 2014 CNS Guidelines on Pediatric Hydrocephalus. With no validated methodology to evaluate the impact of guidelines on clinical practice, we devised a two-tier approach to assess the impact of the guidelines.

METHODS

The study protocol was reviewed and approved by the Institutional Review Board and was exempted from patient consent. Institutional review board approval was obtained for this study. The Pediatric Health Information System (PHIS) was used to obtain national data regarding hydrocephalus practices. This is a diverse 52-pediatric hospital database from the Children's Hospital Association, representative of the various regions of the United States. PHIS primarily consists of academic hospitals (defined in this study as having associated neurosurgery residency programs) with 8 nonacademic hospitals within the database. PHIS contains deidentified patient information on clinical and resource utilization for inpatient, observation unit, ambulatory surgery, and emergency department patient encounters. Key features of this database include patient tracking across multiple encounters of clinical and demographic information, drug utilization, mortality, Current Procedural Terminology codes, and diagnosis and procedure codes using the International Classification of Disease- 9th revision (ICD-9) and 10th revision (ICD-10). This database was queried from 2013 to 2018, with 2013 to 2014 being considered the preguidelines period and 2015 to 2018 being considered the postguidelines period.

Patients included those younger than 18 years with the diagnosis of hydrocephalus defined as having ICD-9 diagnosis codes 331.3, 331.4, 741.0, 742.3, 772.13, or 772.14 or ICD-10 diagnosis codes G91.0, G91.1, G91.3, G91.4, G91.7, G91.8, G91.9, G94.0, G94.1, G94.2, P52.2, Q03, Q05, Q07.02, or Q07.03, excluding the diagnosis of pseudotumor cerebri or normal pressure hydrocephalus. Patients with the ICD-9 procedure code 02.3 or ICD-10 procedure codes 00160J, 00160K, 00163J, or 00164J were codified as ventricular shunt placement patients while patients with ICD-9 procedure code 02.4 or ICD-10 procedure codes of 00P60JZ, 00P63JZ, 0064JZ, 00W60JZ, 00W63JZ, or 00W64JZ were codified as shunt revision patients (inclusive of removal or replacement patients). An important variable in the description of the results was the revision-to-placement ratio, which was defined as the number of shunt revision surgeries divided by the number of new (primary) shunt placement surgeries. This has been previously described in the literature as the Revision Quotient.[12,13] Statistical analyses were performed in SPSS Statistics (version 28.01, IBM).

The use of AICs was evaluated through a data request to 2 of the largest cranial device manufacturing companies who sell competing AICs (personal communication, Integra Codman and Medtronic). This was needed because there is not a Current Procedural Terminology code specific to the use of AICs. While exact sales numbers could not be provided, percentage of sales of antibiotic and nonantibiotic catheters across North America was obtained.

RESULTS

Query of the PHIS database identified 6497 patients who were included in this study. Demographic information is compiled in Table 1, showing a sample similar to the US population (43.4% female, 58.4% White, 18.1% Hispanic/Latino, and 37% having commercial insurance). Identified causes of hydrocephalus were diverse and representative of clinical practice, with 33.4% obstructive, 29.9% congenital hydrocephalus, and 13.4% spina bifida–related hydrocephalus (Table 2).

The PHIS database contained a total of 11 179 shunt procedures between 2013 and 2018 (Table 3). In the preguidelines period of 2013 to 2014, the percentage of shunt revisions (including removals and replacements) of all shunt procedures was 61.9% with a revision-to-placement ratio of 1.63 while in the postguidelines period of 2015 to 2018, the percentage of shunt revisions of all shunt procedures was 45.6% with a revision-to-placement ratio of 0.84 ($P < .0001$).

Sales numbers for ventricular shunt and external ventricular drain catheters were provided by 2 large neurosurgical device companies between the years 2013 and 2021 (Table 4). In this period, Company A saw an increase in proportion of sales of AICs for ventricular shunts from 83% in 2014 to 92% in 2021 and an increase in sales of AICs for external ventricular drains from 0% in 2013 to 77% in 2021. Company B saw an increase in sales of AICs for ventricular shunts from 50% in 2015 to 60% in 2021. Trends demonstrated increased usage of antibiotic-impregnated devices over time.

DISCUSSION

In this study, the evolution of hydrocephalus management over the past decade was assessed through multiple modalities. Based on a nationally representative database, the shunt revision to shunt placement rates decreased in the years after the publication of the 2014 CNS Guidelines on Pediatric Hydrocephalus. The decrease in shunt revision rates is multifactorial and cannot be directly attributed to the publication of the guidelines. Interestingly, the HCRN also demonstrated a decrease in shunt revision rates between 2008 and 2016.[12] The changes from 2013 to 2016 were less dramatic at the 9 HCRN centers studied, with a revision-to-

TABLE 1. Patient Socioeconomic Characteristics

Total number of patients	6497
Average age (mo)	58.5 (67.4)
AAP age groups	
Neonate (<30)	1419 (21.8)
Infancy (≥30 d and <1 y)	1402 (21.6)
Early childhood (≥1 y and <5 y)	1183 (18.2)
Late childhood (≥5 y and <13 y)	1606 (24.7)
Adolescence (≥13 y and <18 y)	887 (13.7)
Sex	
Female	2822 (43.4)
Male	3675 (56.6)
Race	
White	3797 (58.4)
Black	1338 (20.6)
Asian or Pacific Islander	154 (2.4)
Native American	21 (0.3)
Mixed	84 (1.3)
Other	861 (13.3)
Unknown	242 (3.7)
Ethnicity	
Hispanic or Latino	1176 (18.1)
Not Hispanic or Latino	4829 (74.3)
Unknown	492 (7.6)
Predicted median household income (USD)[a]	43 874.0 (16 213.3)
Primary source of payment	
Commercial	2405 (37.0)
Medicaid	3552 (54.7)
Other government[b]	268 (4.1)
Other payer	115 (1.8)
Self-pay	57 (0.9)
Charity or hospital chose not to bill	4 (0.1)
Unknown	96 (1.5)
Child opportunity level	
Very low	1554 (23.9)
Low	1362 (21.0)
Moderate	1335 (20.5)
High	1186 (18.3)
Very high	1010 (15.5)
Unknown	50 (0.8)

AAP, American Academy of Pediatrics; USD, United States Dollar.
[a]Based on 2015 estimation.
[b]Includes CHIP, TRICARE, Medicare, and other government funding.

placement ratio of 1.00 in 2013 to 2014 and 0.92 in 2015 to 2016. This may be because the HCRN centers performed procedure protocolization and techniques to decrease shunt infections that would later be presented in the guidelines and adopted by centers nationally such as those in the PHIS database. The rates of hydrocephalus etiologies in this cohort were noted to be significantly different than previously described in HCRN studies, with a much lower rate of posthemorrhagic hydrocephalus (as noted in Table 2). This may have affected revision rates as it is established that certain etiologies are at higher risk of shunt malfunction.[14] However, given that PHIS is a nationally

TABLE 2. Hydrocephalus Etiology and Comorbidities of Patients

Etiology	
Obstructive hydrocephalus	2173 (33.4)
Congenital hydrocephalus, NOS	1941 (29.9)
Spina bifida with hydrocephalus	870 (13.4)
Communicating hydrocephalus	582 (9.0)
Posthemorrhagic hydrocephalus	422 (6.5)
Hydrocephalus, NOS	406 (6.2)
Posttraumatic hydrocephalus	103 (1.6)
Comorbidity flags	
Cardiovascular	1004 (15.5)
Gastrointestinal	1153 (17.7)
Hematologic or immunologic	180 (2.8)
Malignancy	1065 (16.4)
Metabolic	536 (8.2)
Other congenital or genetic defect	478 (7.4)
Renal and urologic	903 (13.9)
Respiratory	451 (6.9)
Total flags	0.9 (1.1)

NOS, not otherwise specified.

TABLE 3. Trends in Shunt Procedures

	2013 to 2014	2015 to 2018	Total	*P* value
Number of sites	43	50	50	
All shunt procedures	494	10 685	11 179	
Shunt placement	188 (38.1)	5814 (54.4)	6002 (53.7)	
Shunt revision	306 (61.9)	4871 (45.6)	5177 (46.3)	
Revision-to-placement ratio	1.63	0.84	0.86	.0001

representative database, patient etiologies are likely similar between the PHIS and the HCRN databases, but rather in the PHIS database, there is poorer standardization between institutions for etiology coding, so, for example, some patients who should be classified as posthemorrhagic hydrocephalus might be classified as congenital hydrocephalus.

Other nationally representative databases have demonstrated a similar shunt revision-to-placement ratio in the decade before the publication of the guidelines, such as the Kids' Inpatient Database, which was found to have a ratio of 1.91.[13] In countries where medicine is centrally regulated, heavily protocolized, and evidence-based, ratios more similar to the postguidelines period in this study are noted, such as the United Kingdom and Ireland, where a shunt revision-to-placement ratio of 0.96 was observed.[15]

When interpreting these data, it is crucial to understand there are other potential confounding factors which likely led to lower revision rates in the years after the publication of the 2014 CNS Guidelines on Pediatric Hydrocephalus. Among these include the increasing usage of endoscopic third ventriculostomy, improved quality improvement protocols, implementation of AICs, use of image guidance, and employment of endoscopic assistance.[12,15]

TABLE 4. Ventricular Catheter National Percentage Sales

Year	Company A, ventricular shunt catheter sales		Company A, external ventricular drain sales		Company B, ventricular shunt catheter sales	
	Standard	AIC	Standard	AIC	Standard	AIC
2013	—	—	100	0	—	—
2014	17	83	98	2	—	—
2015	16	84	30	70	50	50
2016	15	85	29	71	49	51
2017	14	86	28	72	43	57
2018	12	88	25	75	39	61
2019	11	89	26	74	46	54
2020	9	91	25	75	42	58
2021	8	92	23	77	40	60

AIC, antibiotic-impregnated catheter.

Based on the available data, we cannot directly determine whether the publication of the CNS Guidelines on Pediatric Hydrocephalus had a causative relationship on improved clinical outcomes in the treatment of hydrocephalus. The results based on PHIS database suggest an association with improved shunt outcomes after the publication of the guidelines. The sales of AICs in the years before and after the guidelines also supported potential influence of the guidelines as more surgeons used AICs rather than standard catheters since 2014. It should be noted that there was only a modest increase of approximately 10% in AICs for shunts during this period (much larger increase for AICs for external ventricular drains). Moreover, this type of data is by no means a traditional means of corroborating changes in the surgical technique. Considering all of this, the improvement/change in hydrocephalus care is a very complex finding and certainly not related solely to the guideline publication and the distribution of knowledge regarding evidence-based hydrocephalus management. However, with national trends toward protocolization of care, evidence-based guidelines have an evident and crucial role in distributing and summarizing up-to-date data. It is important to note that many changes in hydrocephalus care would likely have occurred without publication of the guidelines, as the guidelines are based on published medical literature that is readily available to practicing neurosurgeons. The guidelines do reflect a rigorous assessment of the literature, and our findings show a possible correlation between clinical practice and recently published medical literature.

We do think well-done guidelines are a way to rigorously assess and interpret the state of modern medical literature. In this sense, using a guideline to inform a study of clinical practice or patient outcomes might be a good way of evaluating whether the current state of the literature changes the practice of neurosurgery in the United States. It is hard to determine how quickly practice might change when a seminal article is published. While practice change is definitely multifactorial and often related to education from national organizations in addition to focused advertising by device companies, an evaluation of this cause-and-effect relationship may be helpful to understand how our profession evolves over time.

While this is one of the first studies attempting to examine the impact of neurosurgical guidelines, the utility of guidelines is something that has been well documented in nearly all other fields of medicine.[16-21] While individualized patient care is essential, basing practice on evidence-based guidelines often improves patient outcomes. Aside from improving clinical results, guidelines by professional societies have also been used to obtain insurance authorization and justify plans of care.[22,23] Based on the results of this study and evidence in other fields, we believe the production of patient care guidelines in neurosurgery is beneficial to both surgeons and patients. The impact of the CNS guidelines is corroborated by the fact that the CNS guidelines are the most visited pages on the CNS website (personal communication, CNS). We encourage further study of other CNS guidelines to determine the impact on outcomes for other specific patient populations. As guidelines are primarily targeted at clinicians, one useful parameter in gauging the success of a guideline is the degree to which it is used by clinicians. As aforementioned, guidelines can also be critical in bringing about insurance authorization or changes in reimbursement. Thus, conducting a well-designed survey with significant buy-in from recipients and studying insurance and coding trends after guidelines publication may act as other methods to determine the success and utility of clinical guidelines.

Limitations

There are important considerations to recognize when contextualizing the results of this study. Regarding the database portion of the study, a single database system (PHIS) was used, which contained approximately 50 hospitals. While the PHIS database contains a hospital set more diverse than many research groups, there is still some limit in the applicability of these data to hospitals nationwide. Moreover, there appeared to be significantly lower numbers in the preguidelines period of 2013 to 2014 as compared with the postguidelines period, although other national database studies demonstrated similar shunt revision-to-placement ratios during this period. Thus, these results must be interpreted with caution. These lower numbers may be in part due to the novelty of the database and difficulty with database coding as US health care systems converted from ICD-9 to ICD-10 at the end of 2013. There are also significant drawbacks in the granularity of the data from a large national database such as PHIS. For example, the ICD codes used to generate hydrocephalus etiology as reported in Table 2 have little value clinically as conditions such as "congenital hydrocephalus" are poorly defined and not standardized across institutions. More information unavailable in PHIS such as the cause of shunt failure/revision would be useful in the discussion of hydrocephalus trends and the potential impact of the Pediatric Hydrocephalus Guidelines.

Regarding changes in AIC usage, the use of national sales is not a validated method of determining usage so this should be interpreted with caution. When evaluating the AIC sale data, it is also important to consider that AICs cost more than standard catheters and as such, product specialists may be more likely to market these products more heavily, which may have also contributed to changes in the sales seen during this study period.

CONCLUSION

Based on this study, there appears to have been changes in the management of pediatric hydrocephalus since the CNS Guidelines on Pediatric Hydrocephalus were published in 2014. While the publication of the guidelines is unlikely to be directly responsible for the positive changes in hydrocephalus management, there appeared to be an associated improvement in the postguideline period. Improved outcomes are likely associative findings rather than causative with the guidelines representing a culmination of widespread changes in hydrocephalus care such as increased use of ETVs, protocolized care, and image-guided shunt placement. Further research into the impact of clinical practice guidelines is needed to better understand whether this tool is impactful to surgeons and patient care.

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