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Inpatient healthcare burden and variables influencing hydrocephalus-related admissions across the lifespan

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OBJECTIVE The aims of this study were to quantify inpatient healthcare costs, describe patient demographics, and analyze variables influencing costs for pediatric and adult hydrocephalus shunt-related admissions in the US.

METHODS A cross-sectional study was performed using the 2019 Healthcare Cost and Utilization Project Kids' Inpatient Database (KID) and National Inpatient Sample (NIS), nationally representative weighted data sets of hospital discharges for pediatric and adult patients, respectively. *International Classification of Diseases, 10th Revision, Clinical Modification* and *Procedure Coding System* (ICD-10-CM/PCS) code filters for data extraction were queried for admission information. Age at admission was categorized into five groups (≤ 28 days, 29 days to < 1 year, 1–18 years, 19–64 years, and ≥ 65 years).

RESULTS In 2019, there were 36,898 shunt-related hospital admissions accounting for 495,138 hospital days and a total cost of more than $2.06 billion. Initial shunt placements accounted for 53.5% of all admissions and nearly 60% of the total cost.

The median cost per admission was $22,700 and the median length of stay was 5 days. Admissions for shunt infection requiring revision had the highest median cost at $71,300 ($p < 0.001$) and the longest median length of stay at 25 days ($p < 0.001$) compared with initial shunt placements.

By age, admissions that occurred in the first 28 days of life cost almost 5 times more than the median, $110,500 versus $22,700, respectively, and resulted in hospital stays that were 8 times longer than the median, 41 versus 5 days, respectively. Individuals aged ≥ 65 years accounted for 28% of the total shunt-related admissions.

Almost two-thirds (65.3%) of shunt-related admissions were classified as nonelective. The median cost of nonelective procedures was double that of elective admissions, $33,900 versus $15,100, respectively ($p < 0.001$), and resulted in almost 5 times longer hospital stays, 9 versus 2 days, respectively ($p < 0.001$).

Shunt-related admissions were predominantly male across all age groups (54.7%–57.4% male) except the 19- to 64-year age group. In the 19- to 64-year age group, females accounted for 51.1% of admissions. Insurance status was largely age dependent. Of all admissions, 33.1% used private insurance, 32.9% Medicare, and 27.7% Medicaid.

CONCLUSIONS This is the first study to quantify the patient demographics and cost of hydrocephalus shunt-related admissions across the entire age spectrum. Shunt-related admissions cost the US more than $2.06 billion dollars per year and represent only a fraction of the total cost of hydrocephalus care.

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KEYWORDS hydrocephalus; shunt admissions; National Inpatient Sample; Kids' Inpatient Database

Hydrocephalus is a significant medical and financial burden to the healthcare system. The mainstay treatment involves CSF diversion via surgical shunt placement, with more than 30,000 procedures performed annually in the US.[1] However, shunts are plagued with high failure rates, which can lead to significant morbidity and mortality. In fact, > 28% of shunt recipients require revision surgery in the 1st year.[2,3]

ABBREVIATIONS AHCRN = Adult Hydrocephalus Clinical Research Network; AHRQ = Agency for Healthcare Research and Quality; HCRN = Hydrocephalus Clinical Research Network; HCUP = Healthcare Cost and Utilization Project; ICD-10 = *International Classification of Diseases, 10th Revision*; IVH = intraventricular hemorrhage; KID = Kids' Inpatient Database; LOS = length of stay; NIS = National Inpatient Sample; NPH = normal pressure hydrocephalus.

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The financial burden of hydrocephalus is immense and has been well characterized, along with hydrocephalus etiologies and perioperative dynamics in pediatric cohorts but not in adults, who account for nearly 75% of surgical procedures performed for hydrocephalus in the US.[4] Patwardhan et al. estimated that ventricular shunt procedures cost more than $1 billion annually for both the pediatric and adult cohorts combined.[5] However, this study used the National Inpatient Sample (NIS) data from fewer than half the states and, importantly, did not stratify by any hydrocephalus diagnoses. Recent data between 2012 and 2015 from a single pediatric institution demonstrated that the total cost of a successful ventriculoperitoneal shunt was more than $88,000; this cost rose to more than $228,783 in situations of infectious failure.[6] An analysis of the Kids' Inpatient Database (KID) found the average cost for initial shunt placement to be $49,317 ± 74,483 in 2009 and that socioeconomic status, hospital-related factors, and clinical characteristics significantly influenced cost and length of stay (LOS).[7] A study using pediatric data in the early 2000s estimated the overall costs to be in the $1.4 to $2.0 billion range for hospital care including other admissions unrelated to shunt surgery.[8] A recent study of data from 2015 looked at subsequent hospital admissions after initial shunt placement across the spectrum of age and estimated that the hospital charges related to all-cause readmissions were $2.25 billion.[4]

However, across the entire age spectrum, there is tremendous heterogeneity in the etiology of hydrocephalus and patient demographics, which may result in differences in cost, LOS, and eventual outcomes. A granular understanding of factors driving shunt-related admissions may help reduce the significant burden on the healthcare system. Here, we quantify demographics and the cost of shunt-related admissions for hydrocephalus across the entire age spectrum.

Methods

Data Source

This is a retrospective descriptive study based on data from the Agency for Healthcare Research and Quality (AHRQ) Healthcare Cost and Utilization Project (HCUP) National Inpatient Sample (NIS) and Kids' Inpatient Database (KID) databases for the year 2019.

HCUP encompasses the largest collection of all-payer, encounter-level hospital care databases in the US. Among these are NIS and KID, both inpatient care databases, with KID being pediatric specific. NIS data are available annually, and KID data are available every 3 years. The NIS represents a 20% stratified sample of all discharges from US hospitals participating in HCUP, and when weighted, the NIS estimates approximately 35 million hospital stays per year. HCUP-participating hospitals include 4568 US community hospitals from 48 states plus Washington, DC, and records cover 97% of discharges from US community hospitals. The KID is sampled such that 10% of routine births and 80% of complicated births and pediatric discharges are selected, and when weighted, the KID estimates approximately 7 million hospital stays a year.

The KID is specific to patients < 21 years of age. Its sampling design enables more granularity in the study of pediatric conditions. Thus, we decided to use data from the KID for patients < 21 years, and we accordingly excluded patients in this age group from the NIS database to prevent overlap.

Inclusion Criteria

We included all discharges with a shunt-related procedure and a hydrocephalus or shunt-related diagnosis. All diagnoses and procedures were identified using *International Classification of Diseases, 10th Revision, Clinical Modification* and *Procedure Coding System* (ICD-10-CM/PCS) codes. These are listed in Supplementary Tables 1 and 2.

Variables

The main outcomes analyzed were cost and LOS. The NIS and KID contain data on total charges, which is the amount that hospitals bill for services. To reflect the actual expenses incurred by the hospitals, hospital-specific cost-to-charge ratios provided by HCUP were used to convert charges into cost estimates.[9]

Other clinical and demographic variables described include shunt-related admission type, hydrocephalus etiology, age, elective versus nonelective admission, hospital region, sex, race, income level, and expected primary payer. Shunt-related admission-type categories defined include initial placement, revision with infection, revision with malfunction, infection without revision, malfunction without revision, shunt revision only, shunt removal only, shunt irrigation only, and multiple shunt procedures. Details of the ICD-10 codes used in the characterization of admission type and hydrocephalus etiology are described in Supplementary Tables 3 and 4. Hydrocephalus etiology categories defined include tumor-related, intraventricular hemorrhage (IVH), other hemorrhage, meningitis-related, communicating, obstructive, congenital, spina bifida, posttraumatic, normal pressure, and other hydrocephalus. Details of the ICD-10-CM codes used in the characterization of hydrocephalus etiology are described in Supplementary Table 4. If multiple hydrocephalus diagnosis codes were present, the etiology corresponding to the top code was selected for characterizing the admission. If the top code was communicating, obstructive, congenital, spina bifida, posttraumatic, normal pressure, or other hydrocephalus, but one of the latter diagnosis codes indicated a more specific etiology (i.e., tumor, IVH, other hemorrhage, or meningitis), then the more specific etiology was used. Age was categorized as ≤ 28 days, 29 days to < 1 year, 1–18 years, 19–64 years, and ≥ 65 years. All other variables listed above were directly extracted from the original NIS or KID data set. A detailed description of these variables and their categories can be found online (https://www.hcup-us.ahrq.gov/db/nation/nis/nisdde.jsp and https://www.hcup-us.ahrq.gov/db/nation/kid/kiddde.jsp).

Statistical Analysis

All analyses were performed using discharge weights to create national estimates. Descriptive statistics on the number of admissions, total and median costs of admissions, and total and median LOSs are reported for the overall sample and for subgroups characterized by admission type, hydrocephalus etiology, age, elective versus nonelective admission, hospital region, sex, race, income level, and expected primary payer, and Mood's test for the median was used to compare median costs of admissions and median LOSs.[10] A Gaussian generalized linear model with log-link was used to model cost, with hydrocephalus etiology as the main predictor of interest, while adjusting for age group, elective versus nonelective admission, hospital region, sex, race, income level, and expected primary payer as covariates. Similarly, a negative binomial model was used to model LOS with the same independent variables used as in the model for cost.

Postcensus population estimates for 2019 produced by the US Census Bureau were used as reference to compare the race and sex distribution by age groups in this study to the US population using the chi-square goodness-of-fit test. Post hoc tests using exact binomial tests were applied to compare the expected proportion of each individual race to the observed proportion seen in this study. All analyses were performed using Stata (version 14.2, StataCorp) and R (version 4.0.2, The R Foundation for Statistical Computing). All p values ≤ 0.05 were considered statistically significant.

Results

Hydrocephalus Shunt-Related Admissions

In 2019, there were 36,898 admissions accounting for 495,138 hospital days and a total cost of more than $2.06 billion. The median cost per admission was $22,700, and the median LOS was 5 days. Initial shunt placements without infection or malfunction accounted for 53.5% of all shunt-related admissions with a median cost of $24,600 and median LOS of 6 days (Table 1).

Admissions for shunt infection requiring revision represented a minority of admissions (1.54% of total admissions) but had a higher median cost of $71,300 (p < 0.001) and the longest median LOS at 25 days (p < 0.001) compared with initial shunt placements. Shunt malfunction requiring revision accounted for 21.8% of total admissions with a lower median cost of $16,400 (p < 0.001) and shorter median LOS at 2 days (p < 0.001). Other shunt-related problems including infection and malfunction without revision, as well as shunt revision only, shunt removal only, shunt adjustment, or shunt irrigation only, accounted for 24.9% of total admissions. Infection without revision had a higher median cost of $54,700 (p < 0.001) and a longer LOS at 17 days (p < 0.001) compared with admissions for initial shunt placement (Table 1).

Cost and LOS by Hydrocephalus Etiology

The cost and LOS for shunt-related admissions differed by hydrocephalus etiology. Compared with admissions coded for normal pressure hydrocephalus (NPH; reference group), which had the lowest median cost of $15,600 and shortest median LOS of 2 days per admission, shunt-related admissions coded for all other etiologies had higher median costs and longer median LOSs per admission (p < 0.001 for all comparisons) (Table 2). NPH was associated with the highest frequency of initial placement inpatient admissions among the hydrocephalus etiologies investigated and other hydrocephalus with the highest frequency among all shunt discharges (Fig. 1).

In the multivariable analysis, hospital cost and length of stay for patients with spina bifida with hydrocephalus are not shown to be different from cost and LOS for patients with normal pressure hydrocephalus. The multivariable analysis also did not show a statistically significant difference in LOS for congenital hydrocephalus patients and for normal pressure hydrocephalus patients (Supplementary Tables 5 and 6). All other conclusions drawn from Table 2 remain unchanged.

Cost and LOS by Age Group

There were 36,898 admissions coded for age (Fig. 2). Children ≤ 18 years of age accounted for 30.1% (n = 11,124) of total admissions and 37.4% ($773 million) in total costs. Children < 1 year of age accounted for 33.1% (n = 3679) of childhood admissions and 53.6% ($414 million) of the cost (Table 3).

Compared with admissions for children > 28 days to < 1 year of age (reference group), the median cost of admissions that occurred in the first 28 days of life was > 5.5 times more (p < 0.001), $19,400 versus $110,500, respectively, and resulted in hospital stays that were > 13 times longer (p < 0.001), 3 days versus 41 days, respectively. The median cost and LOS for the 19- to 64-year age group were also significantly more than those for the reference group (p < 0.001 for both). For those ≥ 65 years of age, the median LOS (p < 0.001) was slightly longer than that for the reference group, but cost was not different. No differences were seen in median costs between children 29 days to < 1 year and those in the 1- to 18-year age group, while the median (IQR) LOS was slightly longer, 3 (2–13) days versus 3 (1–8) days, respectively (p = 0.006) (Table 3).

Cost and LOS by Admission Type and Hospital Region

Almost two-thirds (65.3%) of shunt-related admissions were classified as nonelective. The median cost of nonelective procedures was more than double that of elective admissions (p < 0.001), $33,900 versus $15,100, respectively, and resulted in 4.5 times longer hospital stays (p < 0.001), 9 versus 2 days, respectively (Table 3).

By region, the South and Midwest hospital regions had significantly lower median costs per admission than the Northeast region (reference group) (p < 0.001 and p = 0.025, respectively), with the South having the highest number of admissions (39.5%). Conversely, the West hospital region had a higher median cost per admission compared with the Northeast region (p = 0.05). All regions had similar LOSs (p > 0.05) (Table 3).

Patient Demographics by Age at Admission

For all shunt-related admissions, there was an overrepresentation of males compared with population estimates provided by the US Census Bureau in 2019 (actual 52.7%, expected 49.2%; p < 0.001). Stratified analyses revealed

TABLE 1. Cost and LOS by shunt-related admission

	No. of Admissions (%)*	Total Cost in $1000s (95% CI)	Median Cost in $1000s (IQR)	Median Cost p Value	Total No. of Hospital Days (95% CI)	Median LOS, Days (IQR)	Median LOS p Value
All	36,898 (0.10%)	2,064,582 (1,880,666–2,248,497)	22.7 (14.1–56.1)	—	495,138 (454,878–535,398)	5 (2–15)	—
Initial placement	19,755 (0.056%)	1,200,628 (1,090,277–1,310,979)	24.6 (14.9–67.7)	Ref	293,405 (268,008–318,802)	6 (2–18)	Ref
Revision w/ infection†	568 (0.0016%)	58,807 (45,874–71,740)	71.3 (42.6–122.8)	**<0.001**	16,527 (13,049–20,006)	25 (21–30)	**<0.001**
Revision w/ malfunction†	8032 (0.023%)	245,759 (215,269–275,889)	16.4 (11.4–27.5)	**<0.001**	53,016 (46,707–59,325)	2 (1–6)	**<0.001**
Infection w/o revision†	1866 (0.0052%)	156,594 (132,393–180,795)	54.7 (30.4–96.7)	**<0.001**	42,136 (36,210–48,062)	17 (10–26)	**<0.001**
Malfunction w/o revision†	3465 (0.0097%)	146,379 (126,904–165,855)	20.7 (14.0–42.4)	**<0.001**	35,037 (29,979–40,095)	4 (2–11)	**<0.001**
Shunt revision only	1394 (0.0039%)	59,714 (45,273–74,155)	19.0 (12.4–36.9)	**<0.001**	12,238 (9550–14,926)	4 (1–9)	**<0.001**
Shunt removal only	572 (0.0016%)	40,064 (27,541–52,586)	32.2 (18.9–79.9)	**0.019**	8592 (6341–10,843)	8 (3–17)	**0.004**
Shunt irrigation only	566 (0.0016%)	63,429 (30,390–96,469)	46.1 (21.7–91.1)	**<0.001**	12,994 (7082–18,906)	14 (6–27)	**<0.001**
Multiple shunt procedures (including shunt adjustment)	1326 (0.0037%)	149,539 (119,637–179,441)	49.0 (21.4–135.9)	**<0.001**	36,178 (29,231–43,125)	13 (4–34)	**<0.001**

Boldface type indicates statistical significance (p ≤ 0.05).
* Based on the percentage of all admissions in the NIS or KID database.
† These admission types are not mutually exclusive. There can be patients who encountered both shunt infection and malfunction, who are included in the counts for both categories.

TABLE 2. Cost and LOS by hydrocephalus etiology

	No. of Admissions (%)*	Total Cost in $1000s (95% CI)	Median Cost in $1000s (IQR)	Median Cost p Value	Total No. of Hospital Days (95% CI)	Median LOS, Days (IQR)	Median LOS p Value
NPH	6632 (18.9%)	127,746 (113,508–141,984)	15.6 (12.3–21.2)	Ref	27,723 (24,092–31,354)	2 (1–5)	Ref
Spina bifida w/ hydrocephalus	2103 (6.0%)	83,098 (68,209–97,987)	19.0 (12.3–39.2)	**<0.001**	18,084 (15,134–21,034)	3 (1–10)	**<0.001**
Congenital hydrocephalus	2786 (8.0%)	157,099 (131,210–182,988)	19.2 (12.6–46.2)	**<0.001**	42,735 (35,694–49,776)	3 (2–12)	**<0.001**
Tumor	5050 (14.4%)	310,699 (269,488–351,910)	31.6 (17.4–63.3)	**<0.001**	68,591 (60,530–76,652)	7 (3–15)	**<0.001**
IVH	1441 (4.1%)	188,314 (158,832–217,796)	85.9 (41.0–159.7)	**<0.001**	49,188 (42,135–56,061)	24 (13–39)	**<0.001**
Other hemorrhage	3976 (11.4%)	499,387 (438,388–560,386)	96.5 (46.8–162.6)	**<0.001**	119,136 (104,198–134,073)	23 (13–37)	**<0.001**
Posttraumatic hydrocephalus	350 (1.0%)	14,930 (10,259–19,600)	24.5 (17.7–46.6)	**<0.001**	4228 (2779–5677)	7 (3–12)	**<0.001**
Meningitis	871 (2.5%)	114,654 (92,977–136,332)	74.7 (44.7–149.2)	**<0.001**	29,096 (24,042–34,151)	23 (14–37)	**<0.001**
Communicating hydrocephalus	2077 (5.9%)	92,178 (75,417–108,938)	20.2 (13.9–39.4)	**<0.001**	22,010 (17,768–26,252)	4 (1–11)	**<0.001**
Obstructive hydrocephalus	3050 (8.7%)	151,566 (130,993–172,139)	25.3 (14.9–56.2)	**<0.001**	37,028 (31,741–42,316)	5 (2–14)	**<0.001**
Other hydrocephalus	6690 (19.1%)	278,697 (243,101–314,293)	19.7 (13.1–38.2)	**<0.001**	64,837 (56,526–73,149)	3 (2–9)	**<0.001**

Boldface type indicates statistical significance (p ≤ 0.05).
* Based on the percentage of all analyzed admissions with hydrocephalus etiology.

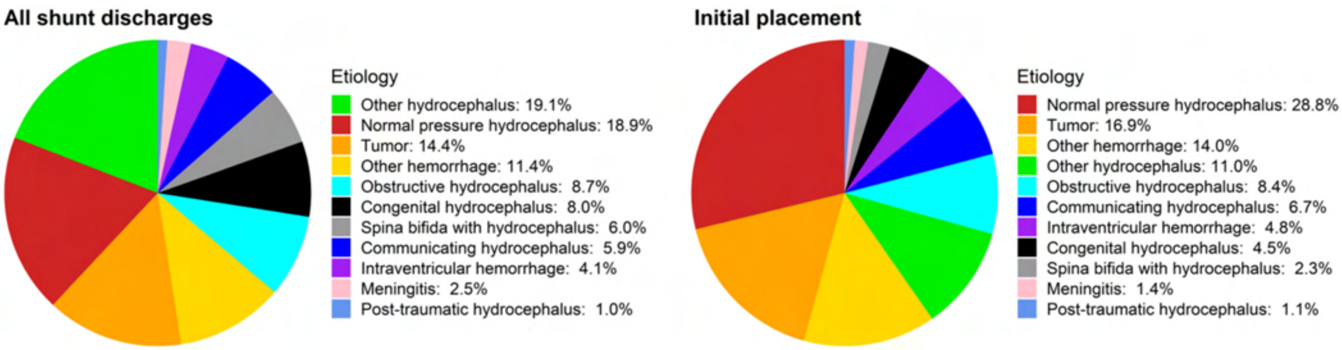
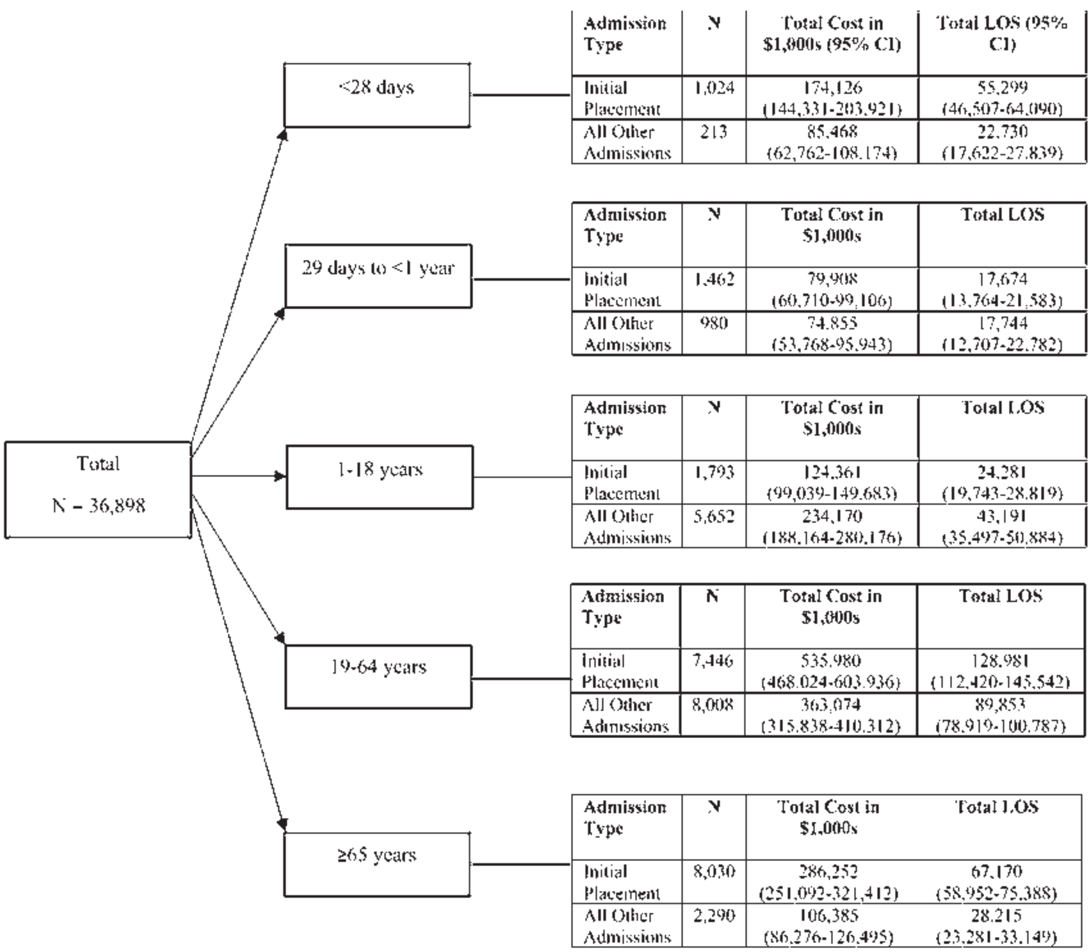


FIG. 1. Pie charts displaying etiology breakdown when considering the full sample of all shunt discharges and a subset of the sample consisting of initial shunt placement discharges only. The percentage of each etiology is shown, ordered from most common etiology to least common.

that this persisted for all age groups except the 19- to 64-year age group, in which there was a slight underrepresentation of males compared with population estimates (19–64 years, $p = 0.021$; all other age groups, $p < 0.001$) (Table 4).

All age groups had significantly different racial compositions than those calculated by the 2019 US Census Bureau (each age group, $p < 0.001$). Post hoc analyses by race and age categories reveal that there was an overrepresentation of African American patients < 65 years of age (each age group < 65 years, $p < 0.001$). However, there were fewer African American patients than expected in the ≥ 65-year group ($p < 0.001$). For Asian/Pacific Islander and Hispanic patients, there were lower than expected ad-



<28 days:

Admission Type	N	Total Cost in $1,000s (95% CI)	Total LOS (95% CI)
Initial Placement	1,024	174,126 (144,331-203,921)	55,299 (46,507-64,090)
All Other Admissions	213	85,468 (62,762-108,174)	22,730 (17,622-27,839)

29 days to <1 year:

Admission Type	N	Total Cost in $1,000s	Total LOS
Initial Placement	1,462	79,908 (60,710-99,106)	17,674 (13,764-21,583)
All Other Admissions	980	74,855 (53,768-95,943)	17,744 (12,707-22,782)

1-18 years:

Admission Type	N	Total Cost in $1,000s	Total LOS
Initial Placement	1,793	124,361 (99,039-149,683)	24,281 (19,743-28,819)
All Other Admissions	5,652	234,170 (188,164-280,176)	43,191 (35,497-50,884)

19-64 years:

Admission Type	N	Total Cost in $1,000s	Total LOS
Initial Placement	7,446	535,980 (468,024-603,936)	128,981 (112,420-145,542)
All Other Admissions	8,008	363,074 (315,838-410,312)	89,853 (78,919-100,787)

≥65 years:

Admission Type	N	Total Cost in $1,000s	Total LOS
Initial Placement	8,030	286,252 (251,092-321,412)	67,170 (58,952-75,388)
All Other Admissions	2,290	106,385 (86,276-126,495)	28,215 (23,281-33,149)

FIG. 2. Total sample is broken down by age group, which is further grouped into initial shunt placement and all other admissions. The number of admissions, total hospital cost (95% CI), and total LOS (95% CI) are reported for each subgroup.

TABLE 3. Cost and LOS by age, admission type, and hospital region

	No. of Admissions (%)*	Total Cost in $1000s (95% CI)	Median Cost in $1000s (IQR)	Median Cost p Value	Total No. of Hospital Days (95% CI)	Median LOS, Days (IQR)	Median LOS p Value
Age							
≤28 days	1237 (0.033%)	259,595 (214,964–304,225)	110.5 (47.2–269.1)	**<0.001**	78,029 (65,806–90,253)	41 (16–99)	**<0.001**
29 days to <1 yr	2442 (0.93%)	154,763 (121,391–188,136)	19.4 (12.3–46.3)	Ref	35,418 (27,994–42,843)	3 (2–13)	Ref
1–18 yrs	7445 (0.52%)	358,531 (292,345–424,717)	19.4 (12.7–43.4)	0.991	67,472 (56,257–78,687)	3 (1–8)	**0.006**
19–64 yrs	15,454 (0.093%)	899,055 (798,950–999,159)	28.0 (15.5–70.9)	**<0.001**	218,834 (195,255–242,413)	7 (2–18)	**<0.001**
≥65 yrs	10,320 (0.077%)	392,638 (345,114–440,161)	19.1 (13.5–35.4)	0.732	95,385 (84,353–106,417)	4 (1–11)	**<0.001**
Admission type							
Nonelective	24,081 (0.084%)	1,736,091 (1,576,795–1,895,386)	33.9 (17.9–83.3)	Ref	435,386 (399,113–471,658)	9 (3–22)	Ref
Elective	12,788 (0.18%)	325,316 (285,644–364,988)	15.1 (11.5–21.4)	**<0.001**	58,613 (51,549–65,677)	2 (1–4)	**<0.001**
Region							
Northeast	6251 (0.097%)	365,928 (273,029–458,827)	25.1 (14.5–62.1)	Ref	85,139 (66,646–103,632)	5 (2–15)	Ref
Midwest	8128 (0.10%)	447,867 (341,727–554,007)	22.1 (14.3–56.1)	**0.025**	106,846 (85,107–128,585)	5 (2–15)	0.154
South	14,562 (0.10%)	695,815 (594,099–797,532)	19.7 (12.8–47.6)	**<0.001**	200,149 (172,855–227,444)	5 (2–15)	0.065
West	7958 (0.11%)	554,971 (445,224–664,719)	28.5 (16.3–72.6)	**0.050**	103,003 (83,059–122,948)	4 (2–15)	0.062

Boldface type indicates statistical significance ($p \leq 0.05$).
* Based on the percentage of all admissions per subgroup in the NIS or KID database.

missions for all age groups (all age groups, $p < 0.001$). For Native American patients, admission rates were not significantly different from population estimates for the population < 65 years. However, admission rates were lower than expected for those ≥ 65 years ($p < 0.001$). For White patients, admission rates were not significantly different than population estimates for those < 1 year of age ($p > 0.05$). However, admission rates were higher than expected for all other age groups (each age group ≥ 1 year, $p < 0.001$). For admissions categorized as "other," rates were higher than expected for all age groups (all age groups, $p \leq 0.05$) (Table 4).

Household Income and Insurance Status by Age at Admission

In Table 5, the percentages of shunt-related admissions for household income quartile were 26.6%, 25.7%, 24.2%, and 23.5% for the first (lowest), second, third, and fourth (highest) quartiles, respectively.

Admissions for children ≤ 28 days of age were more prevalent in the lowest income quartile (32.3%) than the other three quartiles, with the least number of admissions in the highest quartile (16.2%). This general trend was seen for all age groups except the ≥ 65-year group, in which fewer shunt-related admissions were recorded in the lowest income quartile (19.9%) and the most admissions were recorded in the highest income quartile (29.6%).

Insurance status was largely age dependent. Of all admissions, 33.1% used private insurance, 32.9% Medicare, and 27.7% Medicaid. The majority of individuals 0–18 years of age were on Medicaid (53.2%) or private insurance (39.9%). Individuals aged 19–64 years were predominantly on private insurance (45.4%), Medicaid (27.0%), or Medicare (19.0%). Almost 90% of individuals ≥ 65 years were on Medicare (Table 5).

Hydrocephalus Etiology by Age at Admission

As expected for admissions during the first 28 days of life, admissions coded for congenital hydrocephalus (36.1%), spina bifida with hydrocephalus (20.7%), and IVH (17.9%) accounted for three-fourths of the admissions. Similarly, in the oldest age group (≥ 65 years), NPH accounted for the majority of the admissions (57.1%). For the remaining age groups (29 days to < 1 year, 1–18 years, and 19–64 years), an amorphous category of "other hydrocephalus" was the most common (Table 6). While we could not determine a reason for these findings by any additional analysis in the NIS or KID, one speculative hypothesis is that they represent errors in coding the precise subtype of hydrocephalus, and hence a more general code was used, or they could represent patients in which a clear etiology could not be deciphered (e.g., a patient with hydrocephalus due to both trauma and IVH or a patient with obstructive hydrocephalus due to a tumor).

Discussion

This study explored hospital costs, LOS, demographics, etiology, and age distribution of shunt-related hydrocephalus hospital admissions. While individual variables have been studied in select populations, in particular pediatric hydrocephalus, a comprehensive analysis across the lifespan has hitherto been lacking; e.g., the analysis from Simon et al.[8] was restricted to the KID, when approximately 28 states participated over a 3-year period in HCUP, as compared with 48 states and Washington, DC, in 2019 across both the NIS and KID in this analysis. Notably, this permits the analysis of the variance of the influence of different variables on admissions and costs across all age groups.

The methodologies across the different studies vary

TABLE 4. Assigned sex at birth by age and race by age at admission

	All Ages†	≤28 Days	29 Days to <1 Yr	1–18 Yrs	19–64 Yrs	≥65 Yrs
Sex						
Male						
Observed	19,447 (52.7%)	697 (56.3)	1402 (57.4%)	4145 (55.7%)	7553 (48.9%)	5650 (54.7)
Expected§	49.2%	51.2%	51.2%	51.1%	49.8%	44.5%
Female						
Observed	17,451 (47.3%)	540 (43.7%)	1040 (42.6%)	3300 (44.3%)	7901 (51.1%)	4670 (45.3%)
Expected§	50.8%	48.8%	48.8%	48.9%	50.2%	55.5%
p value‡	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.021**	**<0.001**
Race						
African American						
Observed	5134 (14.5%)***	221 (19.5%)***	448 (20.2%)***	1179 (16.8%)***	2551 (17.0%)***	735 (7.3%)***
Expected§	12.5%	13.7%	13.7%	13.7%	13.0%	9.2%
Asian/Pacific Islander						
Observed	1049 (3.0%)***	30 (2.7%)***	70 (3.2%)***	204 (2.9%)***	460 (3.1%)***	285 (2.8%)***
Expected§	5.9%	4.8%	4.8%	5.3%	6.5%	4.7%
Hispanic						
Observed	4571 (12.9%)***	252 (22.3%)**	419 (18.9%)***	1403 (20.0%)***	1872 (12.5%)***	625 (6.2%)***
Expected§	18.5%	26.0%	26.0%	25.5%	18.4%	8.6%
Native American						
Observed	210 (0.6%)*	≤10	24 (1.1%)	50 (0.7%)	109 (0.7%)	20 (0.2%)***
Expected§	0.7%	0.8%	0.8%	0.8%	0.8%	0.6%
White						
Observed	23,179 (65.3%)***	549 (48.5)	1119 (50.4%)	3844 (54.8%)***	9477 (63.1%)***	8190 (80.9%)***
Expected§	60.1%	49.7%	49.7%	50.4%	59.5%	76.1%
Other						
Observed	1376 (3.9%)***	72 (6.4%)*	139 (6.4%)**	339 (4.8%)*	560 (3.7%)***	265 (2.6%)***
Expected§	2.2%	4.9%	4.9%	4.3%	1.8%	0.8%
p value‡	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**

Observed values are given as number (%), and expected values are given as percentages. Boldface type indicates statistical significance (p ≤ 0.05). Counts ≤ 10 are indicated according to the NIS and KID guidelines.
*p ≤ 0.05, **p ≤ 0.01, ***p ≤ 0.001 (post hoc analysis, exact binomial test).
† Based on the percentage of analyzed admissions (observed) or 2019 US Census Bureau data (expected).
‡ Chi-square goodness-of-fit test.
§ Expected proportions are from reference data with age.

TABLE 5. Household income and insurance status by age at admission

	All Ages	≤28 Days	29 Days to <1 Yr	1–18 Yrs	19–64 Yrs	≥65 Yrs
Income level, percentile						
0–25	9677 (26.6%)	398 (32.3%)	765 (31.6%)	2105 (28.6%)	4379 (28.8%)	2030 (19.9%)
26–50	9355 (25.7%)	338 (27.4%)	657 (27.1%)	1845 (25.1%)	4045 (26.6%)	2470 (24.3%)
51–75	8823 (24.2%)	296 (24.0%)	562 (23.2%)	1863 (25.3%)	3432 (22.6%)	2670 (26.2%)
76–100	8538 (23.5%)	200 (16.2%)	439 (18.1%)	1548 (21.0%)	3341 (22.0%)	3010 (29.6%)
Insurance status						
Medicaid	10,192 (27.7%)	720 (58.3%)	1360 (55.8%)	3820 (51.4%)	4162 (27.0%)	130 (1.3%)
Medicare	12,096 (32.9%)	≤10	≤10	≤10	2932 (19.0%)	9150 (88.8%)
No charge	46 (0.12%)	≤10	≤10	≤10	43 (0.28%)	≤10
Other	1436 (3.9%)	60 (4.9%)	143 (5.9%)	385 (5.2%)	633 (4.1%)	215 (2.1%)
Private insurance	12,178 (33.1%)	440 (35.6%)	883 (36.2%)	3103 (41.8%)	6992 (45.4%)	760 (7.4%)
Self-pay	864 (2.3%)	12 (0.97%)	42 (1.7%)	113 (1.5%)	647 (4.2%)	50 (0.49%)

Values are given as number (%) of all analyzed admissions per age category. Counts ≤ 10 are indicated according to the NIS and KID guidelines.

TABLE 6. Hydrocephalus etiology by age at admission

	All Ages	≤28 Days	29 Days–<1 Yr	1–18 Yrs	19–64 Yrs	≥65 Yrs
NPH	6632 (18.9%)	≤10	≤10	≤10	809 (5.7%)	5815 (57.1%)
Spina bifida w/ hydrocephalus	2103 (6.0%)	254 (20.7%)	233 (9.7%)	939 (13.3%)	677 (4.8%)	≤10
Congenital hydrocephalus	2786 (8.0%)	444 (36.1%)	434 (18.1%)	988 (14.0%)	900 (6.4%)	20 (0.20%)
Tumor	5050 (14.4%)	103 (8.4%)	374 (15.5%)	1399 (19.8%)	2324 (16.4%)	850 (8.3%)
IVH	1441 (4.1%)	220 (17.9%)	96 (4.0%)	114 (1.6%)	661 (4.7%)	350 (3.4%)
Other hemorrhage	3976 (11.4%)	11 (0.89%)	161 (6.7%)	265 (3.8%)	2244 (15.9%)	1295 (12.7%)
Posttraumatic hydrocephalus	350 (1.0%)	≤10	≤10	70 (0.99%)	203 (1.4%)	65 (0.64%)
Meningitis	871 (2.5%)	56 (4.6%)	130 (5.4%)	140 (2.0%)	440 (3.1%)	105 (1.0%)
Communicating hydrocephalus	2077 (5.9%)	23 (1.9%)	156 (6.5%)	318 (4.5%)	1055 (7.5%)	525 (5.2%)
Obstructive hydrocephalus	3050 (8.7%)	46 (3.7%)	243 (10.1%)	739 (10.5%)	1577 (11.1%)	445 (4.4%)
Other hydrocephalus	6690 (19.1%)	72 (5.8%)	562 (23.4%)	2080 (29.5%)	3266 (23.1%)	710 (7.0%)

Values are given as number (%) of all analyzed admissions per age category. Counts ≤ 10 are indicated according to the NIS and KID guidelines.

quite considerably in terms of inclusion criteria. We deliberately chose stricter inclusion and exclusion criteria and required that a shunt-related procedure was performed in the same visit in which a hydrocephalus-related diagnostic code was entered. This excluded admissions in which people with hydrocephalus were admitted for unrelated medical conditions but the admission was still coded for hydrocephalus (e.g., a person with hydrocephalus admitted for coronary artery intervention). The propensity for hospitals to upcode to increase reimbursement has been demonstrated in prior NIS analyses.[11] These analyses do not intend to minimize the extensive healthcare burden of people who suffer with hydrocephalus. However, they do help focus the assessment of variables influencing hydrocephalus care primarily, in contrast to the comorbidities.

Initial shunt placements without infection or malfunction accounted for just over 50% of the total shunt-related admissions. This is higher than pediatric data in which initial shunt placement accounted for < 30% of admissions,[8] but it is in line with earlier data from the National Hospital Discharge Survey.[12] This could be due to the inclusion of adult patients who experience lower shunt revision rates[13,14] and/or a decrease in the rate of shunt revisions in the pediatric population over time.[3,15,16]

As expected, admissions for shunt infection with revision had the highest cost and LOS compared with all other admissions. Treating shunt infections is inherently more complex than treating other causes necessitating shunt revision. The same process of removing and replacing the shunt is followed, but additional steps are involved, including putting the patient on antibiotics to clear the infection before the revision surgery, thus prolonging the hospital stay and its attendant morbidity. Infection could also present a variety of severity levels that could impact treatment time and costs. This is supported by the costs associated with infection without revision, which incurred the second highest median cost. While shunt infections represented only a small fraction of total admissions compared with shunt malfunction, they remain a major driver of LOS and costs related to every episode. As such, a previous study mentioned that shunt infection is one of the most costly implant-related infections to treat.[17] The Hydrocephalus Clinical Research Network (HCRN) has standardized a simplified protocol for shunt surgery that has been proven to reduce infections. Wider dissemination and implementation of such protocols would reduce shunt-related infections even further, thus improving patient care and reducing overall costs. The findings from their studies and this analysis could be used to justify the incremental expenses needed to implement such standardized protocols locally at each institution.

Shunt admissions coded for IVH, other hemorrhage, and meningitis represented the highest hospital costs and longest LOSs. This is likely due to the complexity and treatment of comorbid conditions linked to these diagnostic codes. For example, hydrocephalus is known to contribute to increased mortality following IVH and can be an independent predictor of worse outcomes.[18]

Across various age groups, readmissions and reoperations have been studied in previous literature, most notably in a recent paper by LeHanka and Piatt using the 2015 Nationwide Readmissions Database (NRD), a different data source from the one we used.[4] Although the three databases are managed by the AHRQ, there exist some methodological differences in sampling. The emphasis to evaluate the cost, LOS, and patient demographics across the spectrum of age for the entire calendar year, without directly evaluating rates of readmission and reoperations, played a role in our decision to use NIS and KID to obtain more focused data on the selected hypothesis. As examples, race and hospital region are two attributes we assessed that are not present in the NRD data set.

Infants admitted within the first 28 days of life had the highest hospital costs and longest LOSs compared with any other age category, and children < 1 year of age accounted for a disproportionate number of admissions in children ≤ 18 years of age. However, the burden of hydrocephalus in the adult population is clear, with almost 70% of admissions occurring in those ≥ 19 years of age and more than a quarter of all admissions in the ≥ 65-year population. These data highlight that hydrocephalus is not just a pediatric disorder.

In terms of etiology, the expected underlying causes were prevalent at different age groups, with congenital hydrocephalus, spina bifida with hydrocephalus, and IVH dominating in the very young and NPH in the oldest age group, with varying distribution of the etiologies in the groups in between. The sex disparities in all age groups except for the 19- to 64-year group are notable especially in children ≤ 18 years of age (Table 5). It is unlikely that Bickers-Adams syndrome (X-linked hydrocephalus) could explain this difference. This would suggest that other genetic or biological factors remain to be discovered to account for this discrepancy.

This study identified contrasting socioeconomic differences. The proportion of individuals in the lowest quartiles was higher in all age groups except in the ≥ 65-year group. While poverty has been reported to be associated with congenital hydrocephalus in developing countries, it has not been reported in the US. Whether this is mediated by undernutrition, higher perinatal and neonatal infections, low birth weight, or delayed antenatal diagnosis needs to be studied further. The higher representation of the highest quartile in the ≥ 65-year age group is likely a function of access to specialist healthcare for detection and treatment of NPH.

Our study also discovered interesting geographic variations in the cost of care. The median costs were 22% lower in the South as compared with the Northeast ($19,700 vs $25,100; p < 0.001), while median costs were 14% higher in the West than in the Northeast ($28,500 vs $25,100; p = 0.05), despite no statistically significant difference in the median LOS (4 vs 5 days; p = 0.062). Our data set is not enabled to look at outcomes; hence, we cannot estimate if higher spending led to better outcomes. The geographic variation of healthcare delivery and outcomes is a well-researched subject, and it has been demonstrated that supply side, patients' health and income, and patient-specific preferences all play a role.[19]

Our study identified multiple racial disparities across age groups. Both Hispanic and Asian/Pacific Islander patients were underrepresented across all ages. It has been reported that Asians have a lower prevalence estimate for congenital hydrocephalus compared with Whites, but this is the first report that we are aware of showing disparities in admissions for Hispanics and Asian/Pacific Islanders across the lifespan.[20] Conversely, African American patients, White patients, and those identified as "other" are overrepresented in almost every age group except the ≤ 1 year-group (White individuals are at the expected rate) and the ≥ 65-year group (African American individuals are significantly underrepresented). Whether these data reflect underdiagnoses, referral bias, differential genetic risks, differences in racial self-identification, or a combination needs to be investigated.

For those ≥ 65 years of age, the disproportionate number of admissions for White individuals is likely because of the drastic increase in NPH diagnoses. Even though the life expectancy gap between African American and White individuals has narrowed by nearly 50% from 7 years in 1990 to 3.6 years in 2018,[21] the diagnosis and treatment of NPH are heavily skewed toward White individuals, with over 90% of suspected idiopathic NPH patients identifying as White in the multicenter Adult Hydrocephalus Clinical Research Network (AHCRN).[22] This likely underscores a referral bias in the adult population and indicates that many older adults live with undiagnosed NPH.

The healthcare burden associated with inpatient shunt procedures is high, as detailed in our study as well as in other literature. With the current trend toward value-based care and the attempt of policy makers to curb the trajectory of increasing healthcare costs, our study and future studies regarding the topic may provide ways to improve clinical outcomes while lowering costs of care. Our study emphasizes the importance of preventing infections and revisions since they seem to disproportionately affect costs related to hydrocephalus care. In addition, our study identified the socioeconomic and racial discrepancies that likely reflect a barrier to accessing specialty care. These findings in turn will influence future research to further understand the hydrocephalus population, which may influence both clinical care and policy in the future.

Limitations

The NIS and KID are records of admission events, not individual patients, and tracking of individuals over time is not possible. Because there could be multiple admissions for the same patient in a year, the observations are not necessarily independent of each other. Thus, strictly speaking, the independence assumption for the statistical tests used in the analysis do not hold. This is a known limitation and affects all HCUP-related data sets.[23]

A minor limitation is that hospital costs are missing for 0.9% of visits, and LOS data are missing for 0.018% of visits. Thus, total costs and total LOSs are underestimated. Additionally, this report is focused on the cost of shunt-related admissions. Therefore, the cost associated with endoscopic third ventriculostomies is not included.

While a significant portion of the interventions for hydrocephalus are indeed performed in a hospital setting, a considerable proportion of the care of these patients, including imaging studies, neuropsychological assessments, outpatient care, physical and occupational therapy, remedial education, and management of comorbidities, takes place in the outpatient setting. Hence, the true societal and healthcare burden of hydrocephalus is much higher than reported in these analyses.

Although the NIS and KID are not as accurate as well-curated clinical registries (e.g., the pediatric-focused HCRN and AHCRN in the case of adult hydrocephalus), the analysis of large, aggregated data has the potential to examine disparities in care, influence policy decisions, and facilitate quality improvement efforts.[24–26]

Conclusions

This is the first study to quantify the cost of hydrocephalus shunt-related admissions across the entire age spectrum. Conservatively, shunt-related admissions cost the US more than $2.06 billion dollars per year and represent a fraction of the total cost of hydrocephalus care. Despite the limitations of NIS and KID, the large data set facilitates the identification of multiple variables that drive costs and LOS, which in turn identify priorities for future research. Significant work is needed to minimize shunt-related complications. Further research is needed to investigate and rectify the socioeconomic, geographic, and racial disparities identified in these analyses.

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Conception and design: Moghekar, Koschnitzky, Chau, Yerneni, Somera. Acquisition of data: Moghekar, Zhang. Analysis and interpretation of data: Moghekar, Koschnitzky, Zhang. Drafting the article: Moghekar, Koschnitzky, Zhang, Chau. Critically revising the article: Moghekar, Koschnitzky, Yap, Zhang, Yerneni, Somera, Luciano. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Moghekar. Statistical analysis: Zhang. Administrative/technical/material support: Moghekar, Yap, Somera. Study supervision: Moghekar.

Supplemental Information

Online-Only Content

Supplemental material is available with the online version of the article.

Supplementary Tables 1–6. https://thejns.org/doi/suppl/10.3171/2022.10.JNS22330.

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