Impact of Hospital Volume on Outcome After Surgical Treatment for Hydrocephalus: A U.S. Population Study From the National Inpatient Sample

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Abstract

Introduction

Hydrocephalus remains a common condition with significant patient morbidity; however, accurate accounting of the incidence of this disease as well as of the impact of hospital volume on outcome remains limited.

Methods

The National Inpatient Sample was used to evaluate patients who underwent surgical treatment of hydrocephalus from 2009-2013. Patient demographics (e.g., length of stay, disposition, charges), and the impact of hospital volume on outcomes were evaluated.

Results

A total of 156,205 patients were identified. Ventriculoperitoneal (VP) shunting the most common type of device (35.8%) followed by shunt replacement (23.9%). Treatment charges for hydrocephalus were $332 million in 2009 and $418 million in 2013 nationally. High-volume hospitals had more routine discharges compared with lower-volume hospitals (65.7% vs. 50.9%, p<0.0001), which was a trend that improved over time. Multivariate analysis confirmed that hospital volume was independently associated with routine disposition after adjusting for other factors such as patient age, length of stay, and shunt type. However, hospital volume showed a small association with length of stay (β = -0.05, p = 0.0001) and did not impact hospital charges on multivariate analysis.

Conclusion

This analysis provides a recent update of hydrocephalus epidemiology, trends, and outcomes nationally. Estimates from this study suggest that hydrocephalus is a common and costly problem. Hospital volume was for the first time to be associated with important differences in patient outcomes.

Categories: Pediatric Surgery, Neurosurgery, Epidemiology/Public Health
Keywords: hydrocephalus, shunt, incidence, prevalence, epidemiology, disposition, cost

Introduction

Hydrocephalus is a heterogeneous, multifactorial disease resulting from a dynamic imbalance of cerebrospinal fluid (CSF) production and absorption [1]. Regardless of disease etiology, the treatment of hydrocephalus by shunting remains a common strategy. Prior studies have suggested that CSF diversion procedures account for $2-8 billion annually of hospital costs in the U.S. [2, 3] Even with modern biomedical advancements in shunts that increase favorable outcomes, half of all ventricular shunts require revision in the first year, resulting in more surgical procedures with a higher risk of complications [4-7]. Despite how common hydrocephalus is among neurosurgery patients, there is insufficient analysis in the literature of the epidemiology of shunted hydrocephalus as well as the impact of hospital volume on outcomes. The purpose of this study was to use the National Inpatient Sample (NIS) database to better understand the incidence of disease, treatment trends, costs, and impact of hospital volume on the outcomes of CSF shunts in a large population in the U.S.

Materials And Methods

The NIS database, developed by the Healthcare Cost and Utilization Project and funded by the Agency for Healthcare Research and Quality [8, 9], is a nationwide, stratified sample of approximately 20% of inpatient hospital stays including adult and pediatric patients. We used the database to evaluate patients admitted to
The primary outcomes were length of stay, routine disposition, and charges. Patients were divided into those that receive ventriculoperitoneal (VP), ventriculostial, ventriculopleural, lumboperitoneal, or other shunts as well as those who had shunt replacement or removal. Hospital volumes were distinguished into low, middle, and high tiers based on evenly distributing case volumes into thirds for each year. Routine disposition was categorized for patients with home or home health discharges. Hospital charges for all years were adjusted to 2009 levels via the Bureau of Labor Statistics medical price inflation index. Hospital charges were calculated for all patients as well as patients where a shunt procedure was the primary reason for hospitalization.

Mean ± standard deviations are provided for continuous measures. T-tests were used to evaluate continuous variables, while Chi-squared tests were used for discrete variables. Linear and logistic regression were used for the evaluation of continuous or discrete outcomes, respectively, with univariable factors that showed a p<0.2 subsequently entered into multivariable models. Multivariate models aimed to adjust for patient demographics (e.g., patient age) as well as surgical variables (e.g., shunt type). Two-way analysis of variance (ANOVA) with main interaction models was performed for the analysis of outcomes across years. With the known limitations of generating comparisons using large databases, a p<0.0001 was considered, but more importantly, effect size was used to interpret the results [10, 11]. Statistical analysis was performed using SPSS V26.0 (IBM Corp., Armonk, NY, USA). The Strengthening the Reporting of Observational Studies in Epidemiology guidelines were used for the drafting and completion of this paper.

Results

Demographics and outcomes

A total of 156,205 patients from 2009, 2011, and 2013 were included, with approximately equal numbers of patients each year (Table 1, Figure 1). Rates of VP shunt usage increased from 34.7% of cases in 2009 to 36.4% in 2011 and 36.3% in 2013 (Figure 1A). A decrease in shunt replacements was seen from 2009 (26%) to 2013 (22%). The mean length of stay remained stable for all procedure types over time but increased for removal, VP shunts, and lumboperitoneal shunts (Figure 1B). Disposition status also remained fairly stable from year to year, with low clinically relevant differences albeit with some year-to-year fluctuations for different shunt types (Figure 1C). The mean/median charges per patient for shunts increased from 2009 ($117,529/[$48,925] to 2013 ($132,206/$65,795) (Figure 1D); furthermore, patients undergoing VP shunt placement or shunt removal had a more rapid increase in costs over time compared with other shunt placements (Figure 1D). There was a sharp drop in costs for ventriculopleural shunts in 2013. When factoring only primary shunt procedures, the mean/median charges per patient also increased from 2009 ($62,189/$56,516) to 2013 ($82,172/$45,856). In 2009, 2011, and 2013, treatment of hydrocephalus with its associated diseases accounted for $5.9 billion, $7.0 billion, and $7.8 billion (Figure 1E), respectively. Treatment of hydrocephalus alone accounted for $352 million, $590 million and $420 million, respectively. The distribution of patient age and cost demonstrate significant heterogeneity with outlier costs for patients aged <1 year (i.e., neonatal patients) (Figure 2). Pediatric patients were more likely to undergo shunt replacement (57.4% vs. 18.4%, p<0.0001) than adults and more likely to be treated in small/medium, urban teaching hospitals (p<0.0001)(Table 2). In addition, pediatric patients were more likely for home disposition (84.8 vs 49.3%, p<0.0001).

|                          | Lowest volume n = 52945 | Mid volume n = 52085 | Highest volume n = 51174 | P-value |
|--------------------------|-------------------------|----------------------|--------------------------|---------|
| Age, years (mean ± SD)   | 51.6 ± 23.5             | 37.5 ± 27.4          | 31.6 ± 25.6              | <0.0001 |
| Pediatric patients (<18 years) | 5052 (9.6)         | 17029 (32.8)        | 21776 (42.7)             | <0.0001 |
| Admission source         |                         |                      |                          | <0.0001 |
| Routine/birth/other      | 4521 (58.0)             | 4009 (48.8)          | 3092 (58.5)              |         |
| Emergency room           | 2397 (30.8)             | 3230 (39.3)          | 1257 (23.8)              |         |
| Other hospital | 581 (7.5) | 567 (6.9) | 904 (17.1) |
| Other facility | 274 (3.5) | 409 (5.0) | 35 (0.7) |
| Court/law | 19 (0.2) | 5 (0.1) | 0 (0) |
| **Admission type** |  |  | <0.0001 |
| Emergency | 10939 (37.1) | 12761 (42.8) | 11783 (38.9) |
| Urgent | 4701 (16.0) | 6175 (20.7) | 8819 (29.1) |
| Elective | 13082 (44.4) | 10079 (33.8) | 8756 (28.9) |
| Newborn | 367 (1.2) | 442 (1.5) | 492 (1.6) |
| Trauma | 370 (1.3) | 328 (1.1) | 433 (1.4) |
| **Length of stay, days (mean ± SD)** | 11.5 ± 18.5 | 12.6 ± 20.8 | 11.5 ± 19.0 | <0.0001 |
| **Primary payer** |  |  | <0.0001 |
| Medicare | 21974 (41.6) | 13732 (26.4) | 10467 (20.5) |
| Medicaid | 8956 (33.8) | 14299 (31.4) | 16044 (31.4) |
| Private | 17830 (33.8) | 19290 (37.1) | 20953 (41.0) |
| Self-pay | 2091 (4.0) | 2182 (4.2) | 1460 (2.9) |
| No charge | 233 (0.4) | 242 (0.5) | 73 (0.1) |
| Other | 1737 (3.3) | 2300 (4.4) | 2078 (4.1) |
| **Shunt type** |  |  | <0.0001 |
| Ventriculostriatal | 758 (1.4) | 1089 (2.1) | 1341 (2.6) |
| Ventriculopleural | 278 (0.5) | 437 (0.8) | 351 (0.7) |
| Ventriculoperitoneal | 21641 (40.9) | 18412 (35.3) | 15859 (31.0) |
| Lumbaroperitoneal | 1163 (2.2) | 853 (1.6) | 766 (1.5) |
| Replacement | 9968 (18.8) | 13326 (25.6) | 13966 (27.3) |
| Removal | 3322 (6.3) | 3702 (7.1) | 3909 (7.6) |
| Other | 15814 (29.9) | 14264 (27.4) | 14983 (29.3) |
| **Charges (mean ± SD)** | 122311 ± 202061 | 127175 ± 201485 | 128400 ± 201246 | <0.0001 |
| **Hospital bed size** |  |  | <0.0001 |
| Small | 5114 (9.8) | 5412 (10.9) | 770 (1.5) |
| Medium | 15718 (30.0) | 6092 (12.3) | 5386 (10.5) |
| Large | 31604 (60.3) | 38159 (78.8) | 45018 (88.0) |
| **Hospital owners** |  |  | <0.0001 |
| Gov or private-nonprofit | 46661 (89.0) | 48166 (97.0) | 50599 (98.9) |
| Private invest-owned | 5776 (11.0) | 1498 (3.0) | 575 (1.1) |
| **Hospital teaching status** |  |  | <0.0001 |
| Rural | 1885 (3.6) | 849 (1.7) | 0 (0) |
| Urban non-teaching | 19106 (36.4) | 3357 (6.8) | 0 (0) |
| Urban teaching | 31444 (60.0) | 45458 (91.5) | 51174 (100) |
| **Hospital region** |  |  | <0.0001 |
| Northeast | 8419 (15.9) | 8777 (16.9) | 8937 (17.5) |
TABLE 1: Impact of hospital volume on outcomes for hydrocephalus

Values indicate number of patients (percentage) unless otherwise indicated.

SNF, skilled nursing facility
charges over time assessed with two-way ANOVA

A) Numbers of VP shunts increased relative to other types over time (34.7% in 2009 to 36.4% in 2011). Rates of shunt replacements or removals decreased over time. B) Length of stay increased for VP and lumboperitoneal shunt placement, as well as shunt removal relative to other types over time (p<0.0001). C) Routine disposition showed some significant year-to-year fluctuation (p<0.0001), but clinically relevant differences were low. D) Mean charges increased most consistently for VP shunt replacements or removals (p<0.0001). E) Total cumulative charges from 2009 to 2013 are shown for various shunt types.

VP, ventriculoperitoneal; ANOVA, analysis of variance

FIGURE 2: Distribution of cost by age and length of stay

A) Comparison of age and mean charge shows significant outliers driven by large numbers of patients <1 year of age. Patients >1 year up to 100 years show mean charges ranges from $80,000 to $180,000. B) A view of lengths of stay <30 days demonstrated costs ranging from $24,309 to $64,378 for patient lengths of stay 1–7 days, most likely patients with more straightforward shunt placements or replacements.
|                          | Pediatric patients (<18 years) N=43858 | Adult patients (>19 years) N=111843 | P-value |
|--------------------------|----------------------------------------|-------------------------------------|---------|
| **Length of stay, days (mean ± SD)** | 13±26                                  | 11±16                               | 0.0001  |
| **Shunt type**           |                                        |                                     | 0.0001  |
| Ventriculoatrial         | 1554 (3.5)                             | 1629 (1.5)                          |         |
| Ventriculopleural        | 261 (0.6)                              | 793 (0.7)                           |         |
| Ventriculoperitoneal     | 11926 (27.2)                           | 43895 (39.2)                        |         |
| Lumboperitoneal          | 364 (0.8)                              | 2413 (2.2)                          |         |
| Replacement              | 16411 (37.4)                           | 20618 (18.4)                        |         |
| Removal                  | 2823 (6.4)                             | 8096 (7.2)                          |         |
| Other                    | 10519 (24.0)                           | 34398 (30.8)                        |         |
| **Charges (mean ± SD)**  | 120371±232338                          | 128394±188643                       | 0.0001  |
| **Hospital bed size**    |                                        |                                     | 0.0001  |
| Small                    | 5066 (11.8)                            | 6141 (5.6)                          |         |
| Medium                   | 9485 (22.1)                            | 17525 (16.0)                        |         |
| Large                    | 28409 (66.1)                           | 86145 (78.4)                        |         |
| **Hospital teaching status** |                                      |                                     | 0.0001  |
| Rural                    | 360 (0.1)                              | 2366 (2.2)                          |         |
| Urban non-teaching       | 1650 (3.8)                             | 20712 (18.9)                        |         |
| Urban teaching           | 40950 (95.3)                           | 86733 (79.0)                        |         |
| **Hospital region**      |                                        |                                     | 0.0001  |
| Northeast                | 6016 (13.7)                            | 20103 (18.0)                        |         |
| Midwest                  | 10354 (23.6)                           | 26323 (23.5)                        |         |
| South                    | 16293 (37.2)                           | 38566 (34.5)                        |         |
| West                     | 11194 (25.5)                           | 26650 (24.0)                        |         |
| **Disposition**          |                                        |                                     | 0.0001  |
| Routine                  |                                        |                                     |         |
| Home                     | 37198 (84.8)                           | 55081 (49.3)                        |         |
| Home health care         | 3099 (7.1)                             | 12636 (11.3)                        |         |
| Non-routine              |                                        |                                     |         |
| SNF, rehab, or other facility | 2821 (6.4)                            | 38308 (34.3)                        |         |
| Against medical advice   | 10 (0.02)                              | 128 (0.1)                           |         |
| Died in hospital         | 720 (1.6)                              | 5536 (5.0)                          |         |
| Discharged alive, destination unknown | 10 (0.02)                            | 70 (0.1)                             |         |

**TABLE 2: Subgroup analysis of pediatric shunted patients**

The top diagnoses associated with specific shunt procedures were expected and consistent from 2009 to 2013 (Table 3). These included mechanical complications of shunts (966.2), idiopathic normal pressure hydrocephalus (331.5), obstructive hydrocephalus (331.5), infection (996.65), and subarachnoid hemorrhage (430). Disease of hard tissues of teeth (521) was also associated with hydrocephalus but suggested a high rate of incidental findings on head imaging.
| Ventriculoatrial | Ventriculopleural | Ventriculoperitoneal | Replacement | Removal |
|-----------------|------------------|---------------------|-------------|--------|
| Mechanical complication of nervous system device, implant, and graft (966.2) | Mechanical complication of nervous system device, implant, and graft (966.2) | Idiopathic normal pressure hydrocephalus (331.5) | Mechanical complication of nervous system device, implant, and graft (966.2) | Infection and inflammatory reaction due to nervous system device, implant, and graft (996.63) |
| Diseases of hard tissues of teeth (521) | Idiopathic normal pressure hydrocephalus (331.5) | Obstructive hydrocephalus (331.4) | Other complications due to nervous system device, implant, and graft (996.75) | Mechanical complication of nervous system device, implant, and graft (966.2) |
| Infection and inflammatory reaction due to nervous system device, implant, and graft (996.63) | Infection and inflammatory reaction due to nervous system device, implant, and graft (996.63) | Communicating hydrocephalus (331.3) | Infection and inflammatory reaction due to nervous system device, implant, and graft (996.63) | Subarachnoid hemorrhage (430) |

**TABLE 3: Top diagnoses and International Classification of Disease 9 codes associated with hydrocephalus treatment**

**Hospital volume and length of stay**

We compared variables across low-, mid-, and high-volume hospitals (Table 1, Figure 3). A significantly younger population was treated in high-volume compared with medium- or low-volume hospitals (31.6 ± 26.6 years vs. 37.5 ± 27.4 years vs. 51.6 ± 23.5 years, *p*<0.0001), likely reflecting the care of neonatal patients in high-volume centers. High-volume hospitals also had a substantial portion of patients admitted from other hospitals (17.1%) and under emergency (38.9%) or urgent (29.1%) circumstances compared with low- and mid-volume hospitals. Length of stay was not substantially different between low- and high-volume hospitals but was higher for mid-volume hospitals (Figure 3A). High-volume hospitals had more beds, were primarily government or private-nonprofit funded, and were uniformly urban teaching hospitals. High-volume centers were predominantly in the South and West. Routine disposition (e.g., home or home health) was more likely in high-volume hospitals (74.8%) compared with low- (61.9%) or mid-volume (71.9%) hospitals (*p*<0.0001) (Figure 3B). Between 2009 and 2013, overall mean charges increased, although, for low-volume hospitals, the mean charges appear to remain fairly constant between 2011 and 2013 (Figure 2C).
A) Length of stay was similar in low- and high-volume centers but was longer at mid-volume hospitals (p<0.0001). B) Mid- and high-volume centers showed a greater association with routine disposition (p<0.0001). C) Mean costs were statistically significantly but not clinically different depending on hospital volume (p<0.0001). Mean costs showed an increase regardless of hospital volume and remained stable from 2011 to 2013 for lower-volume centers.

ANOVA, analysis of variance

FIGURE 3: Evaluation of outcomes by hospital volumes assessed by two-way ANOVA

Multivariable analysis

Multivariate linear and logistic regression of hydrocephalus outcomes was performed to identify factors associated with length of stay, routine discharge, and charges (Tables 4-6). Multivariate regression showed
that admission source ($\beta = -0.26, p = 0.0001$) and shunt type ($\beta = -0.11, p = 0.0001$) were associated with length of stay (Table 4). Hospital volume did not impact the length of stay. Multivariate logistic regression suggested that admission via the emergency room (odds ratio [OR] = 0.32, $p = 0.0001$) or other facility (OR = 0.25, $p = 0.0001$) was associated with lower rates of routine disposition (Table 5). Similarly, each of the payer types, except self-payers, showed lower rates of routine disposition (range OR = 0.73-0.84) compared with no charge patients (OR = 3.4). Although all shunt types were associated with routine disposition, ventriculopleural (OR = 2.88) and lumboperitoneal (OR = 1.98) shunts showed the highest association with routine disposition. Interestingly, the placement of a VP shunt (OR = 1.16) showed a lower association with routine disposition compared with shunt replacement (OR = 1.5). Middle- and high-volume hospitals showed a greater association with routine disposition while low-volume hospitals failed to show a strong association with routine disposition after adjusting for other factors. Multivariate logistic regression showed that only length of stay was significantly associated with hospital charges ($\beta = 0.75, p = 0.0001$) (Table 6).

| | Univariate | Multivariate |
|---|---|---|
| | Standardized β value | P-value | Standardized β value | P-value |
| Age | -0.067 | 0.0001 | -0.065 | 0.0001 |
| Admission source | -0.2 | 0.0001 | -0.26 | 0.0001 |
| Admission type | -0.074 | 0.0001 | 0.007 | 0.6 |
| Primary payer | 0.037 | 0.0001 | -0.25 | 0.04 |
| Shunt type | -0.027 | 0.0001 | -0.11 | 0.0001 |
| Hospital bed size | 0.015 | 0.0001 | -0.048 | 0.0001 |
| Hospital owners | -0.009 | 0.0001 | -0.004 | 0.7 |
| Hospital teaching status | 0.054 | 0.0001 | 0.063 | 0.0001 |
| Hospital region | -0.016 | 0.0001 | 0.022 | 0.09 |
| Hospital volume | -0.001 | 0.8 | 0.8 |
| Year | 0.008 | 0.001 |

### TABLE 4: Evaluation of factors affecting length of stay

| | Univariate | Multivariate |
|---|---|---|
| | OR (95% CI) | P-value | OR (95% CI) | P-value |
| Age | 0.965 (0.964, 0.965) | 0.0001 | 0.962 (0.960, 0.964) | 0.0001 |
| Admission source | | | | |
| Emergency room | 0.36 (0.33, 0.38) | 0.0001 | 0.32 (0.3, 0.35) | 0.0001 |
| Other hospital | 0.22 (0.2, 0.24) | 0.0001 | 0.23 (0.21, 0.26) | 0.0001 |
| Other facility | 0.13 (0.11, 0.15) | 0.0001 | 0.13 (0.1, 0.15) | 0.0001 |
| Court/law | 0.34 (0.15, 0.75) | 0.008 | 0.43 (0.17, 1.11) | 0.08 |
| Routine/birth/other | Reference | Reference |
| Admission type | | | | |
| Emergency | 1.76 (0.49, 6.4) | 0.4 | | |
| Urgent | 1.86 (0.51, 6.73) | 0.3 | | |
| Elective | 3.62 (0.998, 13.13) | 0.05 | | |
| Newborn | 7.22 (1.97, 26.46) | 0.003 | | |
| Trauma | 0.28 (0.08, 1.03) | 0.06 | | |
| Other                  | Reference | Length of stay | 0.97 (0.967, 0.968) | 0.0001 | 0.96 (0.958, 0.962) | 0.0001 |
|-----------------------|-----------|----------------|---------------------|--------|---------------------|--------|
| Primary payer         |           | Medicare       | 0.38 (0.36, 0.4)   | 0.0001 | 0.73 (0.6, 0.91)    | 0.004  |
|                       |           | Medicaid       | 1.43 (1.34, 1.52)  | 0.0001 | 0.75 (0.61, 0.92)   | 0.006  |
|                       |           | Private        | 1.07 (1.006, 1.14) | 0.03   | 0.77 (0.63, 0.92)   | 0.01   |
|                       |           | Self-pay       | 0.86 (0.79, 0.93)  | 0.0001 | 0.84 (0.63, 1.11)   | 0.2    |
|                       |           | No charge      | 0.997 (0.817, 1.217)| 0.98   | 3.4 (1.47, 7.98)    | 0.004  |
| Other                 | Reference | Shunt type     | Venticuloatrial    | 2.94 (2.18, 2.62) | 0.0001 | 1.28 (0.995, 1.652) | 0.06   |
|                       |           |                | Venticulopleural   | 1.37 (1.2, 1.67)  | 0.0001 | 2.88 (1.76, 4.69)   | 0.0001 |
|                       |           |                | Venticuloperitoneal| 0.94 (0.91, 0.96) | 0.0001 | 1.16 (1.07, 1.27)   | 0.01   |
|                       |           |                | Lumboperitoneal    | 3.39 (3.03, 3.78) | 0.0001 | 1.98 (1.44, 2.71)   | 0.0001 |
|                       |           | Replacement    | 2.63 (2.55, 2.72) | 0.0001 | 1.5 (1.35, 1.67)    | 0.0001 |
|                       |           | Removal        | 0.82 (0.79, 0.86) | 0.0001 | 0.89 (0.78, 1.02)   | 0.09   |
|                       | Reference | Charges        | -                   | -      | -                   | -      |
| Hospital size         |           | Small          | 1.77 (1.69, 1.86)  | 0.0001 | 1.64 (1.41, 1.91)   | 0.0001 |
|                       |           | Medium         | 1.23 (1.19, 1.26)  | 0.0001 | 1.09 (0.98, 1.21)   | 0.1    |
|                       | Reference | Hospital owners| Gov or private     | 1.38 (1.32, 1.45)| 0.0001 | 1.49 (1.1, 1.91)    | 0.0001 |
|                       |           | Urban non-teaching | 0.66 (0.64, 0.67) | 0.0001 | 1.08 (0.98, 1.18)   | 0.1    |
|                       |           | Urban teaching  | Reference           | -      | -                   | -      |
| Hospital teaching status|         | Rural          | 0.82 (0.76, 0.89)  | 0.0001 | 1.14 (0.89, 1.44)   | 0.3    |
|                       |           | Urban non-teaching | 0.66 (0.64, 0.67) | 0.0001 | 1.08 (0.98, 1.18)   | 0.1    |
| Hospital region       |           | Northeast      | 0.66 (0.64, 0.68)  | 0.0001 | 0.57 (0.5, 0.64)    | 0.0001 |
|                       |           | Midwest        | 0.85 (0.83, 0.88)  | 0.0001 | 0.52 (0.43, 0.62)   | 0.0001 |
|                       |           | South          | 1.09 (1.06, 1.12)  | 0.0001 | 0.77 (0.69, 0.86)   | 0.0001 |
|                       | Reference | West           | Reference           | -      | -                   | -      |
| Hospital volume       |           | Low            | 0.54 (0.53, 0.56)  | 0.0001 | 0.99 (0.88, 1.12)   | 0.9    |
|                       |           | Medium         | 0.86 (0.84, 0.88)  | 0.0001 | 1.27 (1.13, 1.43)   | 0.0001 |
| Year                  |           | 2009           | 1.02 (0.99, 1.05)  | 0.1    |                     |        |
TABLE 5: Evaluation of factors affecting routine disposition
OD, odds ratio; CI, confidence interval

|                      | Univariate |           | Multivariate |           |
|----------------------|------------|-----------|--------------|-----------|
|                      | Standardized β value | P-value | Standardized β value | P-value |
| Age                  | -0.01      | 0.0001    | -0.005       | 0.5       |
| Admission source     | -0.26      | 0.0001    | -0.1         | 0.0001    |
| Admission type       | -0.069     | 0.0001    | 0.039        | 0.0001    |
| Length of stay       | 0.8        | 0.0001    | 0.75         | 0.0001    |
| Primary payer        | 0.048      | 0.0001    | 0.053        | 0.0001    |
| Shunt type           | -0.019     | 0.0001    | 0.036        | 0.0001    |
| Hospital size        | 0.023      | 0.0001    | 0.052        | 0.0001    |
| Hospital owners      | 0.039      | 0.0001    | 0.003        | 0.6       |
| Hospital teaching status | 0.045   | 0.0001    | 0.063        | 0.0001    |
| Hospital region      | 0.025      | 0.0001    | -0.132       | 0.0001    |
| Hospital volume      | 0.012      | 0.0001    | -0.05        | 0.0001    |
| Year                 | 0.03       | 0.0001    | 0.009        | 0.3       |

TABLE 6: Evaluation of factors affecting charges

Discussion

National trends

These results help inform regarding the number of procedures used to treat hydrocephalus annually (~50,000) and the net cost of this disease ($418 million in 2013). These results also help break down patient characteristics, hospital types, and regional differences related to hydrocephalus treatment. High-volume hospitals did not have a substantially lower length of stay or lower charges, but despite having a higher rate of urgent and emergent admission sources, they did show higher rates of routine disposition. In addition, the greater likelihood of routine disposition in high-volume hospitals increased over time compared with the lowest volume hospitals. High-volume hospitals were also more prevalent in the South and West, suggesting geographic variation in patient outcomes and access to care. Evaluation of hospital regions showed that hospitals in the South were more likely to have lower mean charges and greater routine disposition compared with other regions (Figure 4). These findings remained evident in multivariate analysis which attempted to account for some patient heterogeneity.
The total numbers of surgically treated hydrocephalus cases from 2009 to 2013 are shown along with mean length of hospital stay, mean charges, and rates of routine disposition. Lower mean charges and higher rates of routine disposition were more likely in the South compared with other regions, which correlated with the higher prevalence of high-volume centers in this region.

**Epidemiology of hydrocephalus treatment**

Various studies have aimed to evaluate the incidence, prevalence, and cost of hydrocephalus treatment. Most have used single-center studies evaluating specific etiologies of hydrocephalus [7, 12]. Bondurant et al. [13] reported one of the first database studies in 1995, citing a prevalence of 125,000 shunts in the U.S., 69,000 discharges annually with hydrocephalus diagnosis, 36,000 annual shunt-related procedures, and an annual expenditure of $100 million per year. These authors admitted the challenges of identifying accurate epidemiological data for hydrocephalus treatment, and their results are likely underestimates of the true incidence and cost. Another study estimating rates of normal pressure hydrocephalus suggested an incidence of 1.2:1000 inhabitants annually, which was much higher than prior estimates [14]. Interestingly, this study predicted that the incidence of shunt-related surgery for normal pressure hydrocephalus was between 1 and 2:100,000 inhabitants annually, suggesting a highly underdiagnosed and undertreated disease. The underdiagnosis of normal pressure hydrocephalus has been shown in other large studies [15]. More recent studies have aimed to use multicenter registries to evaluate hydrocephalus incidence and complication profiles [16, 17].

Global estimates of hydrocephalus suggest a higher incidence - 145:100,000 births in Africa and 316:100,000 births in Latin America compared with 68:100,000 births in the U.S. using data from a meta-analysis [18]. That study predicted 400,000 new cases of pediatric hydrocephalus annually with disproportionate rates in low- and middle-income countries. Others have verified the challenges for global surgery in addressing pediatric hydrocephalus [19, 20].

The most recent study from the NIS in 2000 identified 5,574 admissions and helped characterize shunt types, hospital characteristics, and costs [2]. Most shunts were VP shunts (43.4%), while most admissions were elective (43.3%) for treatment of shunt malfunction (40.7%). A mean cost of $35,816 was identified per case, which predicted a $1.1 billion annual cost in the U.S. for treatment. Approximately 20% of cases cost more than $50,000, and 10% cost more than $100,000, suggesting inclusion of other diagnostic codes similar to our series. Nonetheless, hydrocephalus treatment accounted for significant healthcare expenditure. Our results further clarify this study by also studying primary shunt procedures alone, data over recent years, and involved a more comprehensive list of International Classification of Diseases 9 codes for including and studying patients. In addition, our results are the first to consider the impact of hospital volume on patient impact.

**Outcomes and healthcare disparities by hospital characteristics**

Variation in hospital volume, type, and region had impacts on hydrocephalus treatment despite shunts being a common procedure across all neurosurgery. In a series of 375 pediatric patients treated for hydrocephalus, Walker et al. [21] showed that those with public insurance stayed in the hospital an average of five days longer and were more likely to be transferred from other hospitals, to be born prematurely, and to present with a neoplasm. These results suggest some socioeconomic disparity in access to hydrocephalus treatment. Our results help to explore some of the regional differences in treatment and suggest that admissions via the emergency room and birth admission, in particular, were associated with lower length of stay, which may suggest that earlier treatment may improve outcomes. However, the younger mean age of
patients in high-volume hospitals suggests that the care for neonatal patients occurs in these institutions. Despite the increased complexity of these patients, higher-volume hospitals were still overall able to achieve higher rates of routine disposition. Accessibility of hydrocephalus and other disease treatment in urban teaching institutions and by geographic region has been shown in other studies [2, 4, 22].

Limitations
Limitations of this study mainly surround the use of an administrative database. Although this information provides population-level estimates, variables are dependent on coding and may include heterogeneous groups of patients. Our estimates of mean, median, and total cost for hydrocephalus treatment vary from some prior studies. Several reasons for this may be that this study has been more inclusive of different treatment modalities, includes a database predicting the national population, and involves the use of hospital charges. Further economic modeling would be needed to more accurately determine the cost of hydrocephalus treatment. One of the challenges with this data involved the heterogeneity of diagnoses requiring shunt treatment due to the use of multiple diagnostic codes within the NIS for each individual patient. Additionally, P-values in our study were frequently significant at a 0.05 level, likely because of the very large sample sizes in this study. With the known limitations with generating comparisons using large databases, a p<0.0001 was considered, but more importantly, effect size was used to interpret the results. Rather than simply using P-values, we utilized the effect size, including β coefficients, in multivariate analysis to analyze group differences.

Conclusions
This analysis provides a recent update of hydrocephalus epidemiology, trends, and outcomes nationally. Shunt treatment for hydrocephalus involves up to 50,000 cases a year. In addition, hydrocephalus treatment is implicated alone or in combination with other diseases to a cost of $418 million annually in the U.S. Despite being a relatively common disease, hydrocephalus treatment and patient outcomes are impacted by types of hospitals and surgeon volume. Even with more complex cases in higher volume centers, routine disposition was more common. In addition, the increased complexity of neonatal care and hydrocephalus management has likely also pushed towards the increased treatment of hydrocephalus in tertiary care centers. Nonetheless, hydrocephalus treatment remains one of the most common procedures in neurosurgery where the availability of surgical treatment options and management in lower-volume (e.g., community) hospitals will be critical to meeting the need of this patient population. These data suggest that hospital volume does impact care and that there is an opportunity for improving gaps in outcomes. Further study is needed to identify sources of these gaps and potentially improve patient treatment.

Additional Information
Disclosures
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