



Original Article

Ten-year review of neonatal neurosurgical outcomes and cost analysis

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ABSTRACT

Background: Neurosurgical interventions in neonates may contribute to increased neonatal intensive care unit (NICU) stay. The impact of neurosurgical interventions on length of stay (LOS) and cost is not well-documented in the literature. In addition to LOS, other factors may impact overall resource utilization. Our objective was to perform a cost analysis of neonates who underwent neurosurgical procedures.

Methods: A retrospective chart review was performed on NICU patients who underwent ventriculoperitoneal and/or subgaleal shunt placement between January 1, 2010, and April 30, 2021. Postoperative outcomes were analyzed, including LOS, revisions, infections, emergency department (ED) visits following discharge, and readmissions accounting for health care utilization cost.

Results: Sixty-six neonates underwent shunt placement during our study period. Out of our 66 patients, 40% of infants had intraventricular hemorrhage (IVH). About 81% had hydrocephalus. Specific diagnoses for our patient population varied and included: 37.9% of patients had IVH complicated by posthemorrhagic hydrocephalus, 27.3% had Chiari II malformation, 9.1% had a cystic malformation leading to hydrocephalus, 7.5% had solely hydrocephalus or ventriculomegaly, 6.0% had myelomeningocele, 4.5% had Dandy-Walker malformation, 3.0% had aqueductal stenosis, and the remaining 4.5% had varying other pathologies. In our patient population, 11% of patients had an identified or suspected infection within 30 days after surgery. The average LOS was 59 days versus 67 days for patients with a postoperative infection. Number of patients who visited the ED within 30 days of discharge was 21%. Of these ED visits, 57% led to readmission. Complete cost analysis was available for 35 out of 66 patients. The average LOS was 63 days with average cost of admission of \$209,703.43. Average cost for readmission was \$25,757.02. Average daily cost for neurosurgical patients was \$1,672.98 versus \$1,298.17 for all NICU patients.

Conclusion: Neonates who underwent neurosurgical procedures had longer LOS as well as higher daily cost. LOS for infants with infections following procedures was increased by 10.6%. Further research is needed to optimize health-care utilization for these high-risk neonates.

Keywords: Hydrocephalus, Length of stay, Neonates, Readmissions, Ventriculoperitoneal shunt

INTRODUCTION

Hydrocephalus in children results from impaired cerebrospinal fluid (CSF) resorption or CSF obstruction. Hydrocephalus is one of the most common conditions requiring procedural intervention by pediatric neurosurgeons. Nearly 400,000 cases of pediatric hydrocephalus present each year globally, with a global prevalence of 85/100,000.^[8] Ventriculoperitoneal (VP) shunting is

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one of the most common methods chosen to divert CSF, with approximately 33,000 shunt procedures performed across both pediatric and adult patients annually in the United States.^[10]

Despite the advances in shunt technology, there are several potential complications of shunt placement surgery, including infection, migration, obstruction, mechanical failure, under-drainage, and over-drainage.^[4,10] These complications often lead to readmissions, increased financial burden, and revision surgeries which may negatively impact patients' quality of life.^[1,10] The rate of revision surgeries is reported to be as high as 67%, with most studies reporting a higher number of shunt revisions and replacements among pediatric patients compared to adults.^[1,5,12] These studies also demonstrated that pediatric patients born at <40 weeks of gestation are at even higher risk of shunt failure.^[7]

Complications of shunt placement in neonates may lead to a prolonged length of stay (LOS) and cost of admission in the neonatal intensive care unit (NICU). These potential sequelae may also negatively impact morbidity and mortality in this high-risk population. Complications are well-documented, but there is a dearth of literature on the impact of neurosurgical interventions on the length of NICU stay and cost of admission. Importantly, cost may also be influenced by other factors independent of LOS alone.

To fill this gap, we performed a cost analysis of NICU hospitalization, 30-day readmissions, and emergency department (ED) visits for neonates who underwent VP and/or subgaleal shunt placement during the initial NICU admission. Studying and optimizing these metrics have become crucial during a pandemic.

MATERIALS AND METHODS

This study was approved by the institutional review board. We conducted a retrospective review between January 1, 2010, and April 30, 2021, at a tertiary care center in an urban hospital in the Midwest. A total of 66 patients were included in the study. Infants who underwent either a VP shunt or subgaleal shunt placement during initial hospitalization from birth in the NICU were included in the study. Patients who had shunts placed after initial discharge home from the hospital, or any infants with central nervous system (CNS) abnormalities not requiring surgical intervention were excluded from the study.

Study variables included admission type, birth weight in grams, gestational age at birth in weeks, discharge corrected gestational age (CGA), number of gestations per pregnancy, size for gestational age, sex, race, delivery type, indication for delivery, maternal risk factors, Apgar scores, LOS, disposition upon discharge, discharge weight in grams, grade of intraventricular hemorrhage (IVH), presence of hydrocephalus, requirement of VP shunt placement, subgaleal shunt placement, shunt placement and revision time, infection after shunt placement,

type of infection, timing of infection, seizures pre and post shunt placement, bleed after shunt placement, requirement of gastrostomy tube placement, respiratory support at time of discharge, requirement of tracheostomy, congenital anomalies or genetic syndromes, 30 day readmission, ED visits within 30 days of discharge, and requirement of direct admission from clinic, as well as dates and CGA of all events [Table 1].

Data analysis was performed through the institution's Clinical Informatics and Biostatistics Department using descriptive statistics with R 4.1.3 software. Cost data were obtained through the institution's financial analysis team. Consistent definitions and costing methodology available since 2015 were used to complete cost analysis for 35 out of 66 patients. These data were utilized to calculate the average daily cost of admission, ED visits, and readmissions for our patient population. In addition, cost analysis of average neonatal patients in NICU was obtained for comparison purposes during the study period.

RESULTS

Sixty-six neonates were included in our study. A total of 52 (78.8%) patients were in-born and 14 (21.2%) were transferred to our NICU from other institutions [Table 1]. 40% ($n = 27$) of the infants had IVH (Grade I–IV) [Figure 1]. Papile classification was utilized for grading of IVH. 81% ($n = 54$) of the patients had hydrocephalus. Diagnoses in our patient population varied and included the following: 37.9% ($n = 25$) of patients had IVH complicated by posthemorrhagic hydrocephalus, 27.3% ($n = 18$) had Chiari II malformation, 9.1% ($n = 6$) had a cystic malformation leading to hydrocephalus, 7.5% ($n = 5$) had solely hydrocephalus or ventriculomegaly, 6.0% ($n = 4$) had myelomeningocele, 4.5% ($n = 3$) had Dandy-Walker malformation, 3.0% ($n = 2$) had aqueductal stenosis, and the remaining 4.5% ($n = 3$) had varying other pathologies. The case with Grade I IVH that progressed to hydrocephalus was in the setting of concern for non-accidental trauma. Average weight at time of VP shunt placement was 3033.45 g, with a range of 1690–6385 g. CGA on day of VP shunt placement distribution is skewed left. Average weight at time of subgaleal shunt placement was 1482 g, with a range of 1100–2100 g. CGA on day of subgaleal shunt distribution is skewed right. About 11% ($n = 7$) had an identified or suspected infection within 30 days after surgery. Of those seven patients, 71% ($n = 5$) had an infection within the first 14 days following shunt placement [Table 1]. CGA on day of infection is normally distributed, CGA on day of shunt revision is normally distributed; however, CGA on day of shunt revision is skewed right.

The average LOS was 59 days for all 66 neonates. For the seven patients who had an infection, average LOS was 67 days. For the remaining 59 patients, the average LOS was 58 days. Fifteen out of our 66 neonates who had prenatal diagnoses had a LOS of 20 days or less. Average LOS across all NICU patients in our institution from October 2018 to

Table 1: Patient Demographics	
Demographics	N=66
Gender	
Female	22 (33.33%)
Male	44 (66.67%)
Admit type	
Inborn	52 (78.79%)
Outborn	14 (21.21%)
Number of fetuses per gestation	
1	53 (80.30%)
2	11 (16.67%)
3	8 (12.12%)
Grade of IVH	
None	39 (59.09%)
Grade I	1 (1.52%)
Grade II	5 (7.58%)
Grade III	11 (16.67%)
Grade IV	10 (15.15%)
Prenatal Diagnosis	
Yes	39 (59%)
No	27 (41%)
Size for gestational age	
SGA	11 (16.67%)
AGA	47 (71.21%)
LGA	8 (12.12%)
Race	
African American	21 (31.82%)
White	20 (30.30%)
Hispanic/Latinx	21 (31.82%)
Other	4 (6.06%)
Route of delivery	
SVD	18 (27.27%)
C/S	47 (71.21%)
Unknown	1 (1.52%)
Birthweight (g) mean (SD) (min, max)	2,417 (1,182), (460.00, 4,505)
Gestational age (week), mean (SD), (min, max)	33.76 (5.47), (23.28, 40.57)
Disposition	
Home	59 (89.39%)
Transfer	6 (9.09%)
Died	1 (1.52%)
Discharge weight (g), mean (SD), (min, max)	3,831.97 (1,023.20), (2,145, 8,050.0)
Length of stay (LOS) day, mean (SD), (min, max)	59.17 (48.16), (8.00, 219.00)
Discharge CGA, mean (SD), (min, max)	42.66 (3.96), (36.71, 57.86)

N: Number of participants included in this study, SGA: Small for gestational age, AGA: Average for gestational age, LGA: Large for gestational age, SVD: Spontaneous vaginal delivery, C/S: Cesarean Section, CGA: Corrected gestational age, IVH: Intraventricular Hemorrhage, SD: Standard deviation.

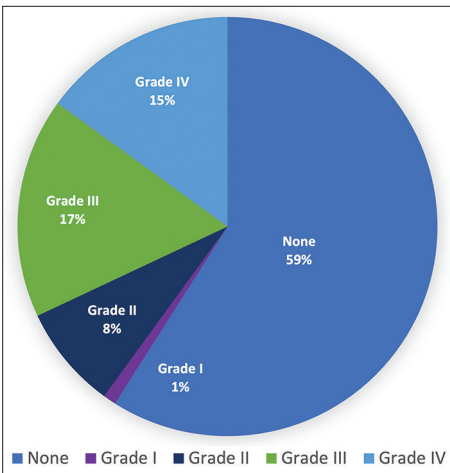


Figure 1: Grades of intraventricular hemorrhage in study population.

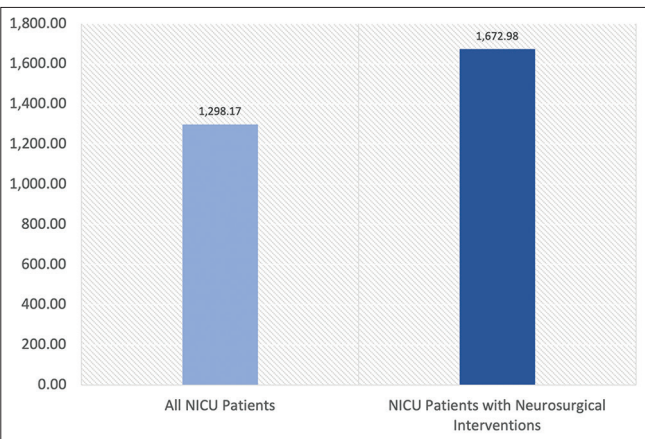


Figure 2: Average direct cost per patient day comparing all neonatal intensive care unit (NICU) patients versus NICU patients undergoing neurosurgical interventions.

April 2021 was 22.73 days. Following discharge from the NICU, 21% of patients (n = 14) presented to the ED within 30 days of discharge. Of these 14 ED visits, 57% (n = 8) led to

readmission. Of the total 10 readmissions, 2 (20%) were direct admissions from clinic.

The average LOS for the 35 patients for whom a complete cost analysis was completed was 63 days. Average LOS for all NICU patients from 2018 to 2021 was 22 days. The average cost of admission for the available study patients was \$209,703.43 with a range of \$28,515.51–\$1,491,942.40. Average daily cost for our patient population was \$1,672.98, whereas average daily cost for all NICU patients was \$1,298.17. Five patients required readmission with an average cost of readmission \$25,757.02 ranging from \$1,998.71 to \$56,805.36 [Figure 2]. Distribution of cost per patient day was not normally distributed. Cost included direct and indirect costs for the entirety of admission. Information was collected from organization’s financial data mart. Costing definitions and methodology have been the same since 2015.

DISCUSSION

To the best of our knowledge following review of available literature, this is the first study to show cost analysis in neonates with neurosurgical procedures. We examined patient outcomes for neonates having undergone neurosurgical procedures in our NICU with particular emphasis on how outcomes impact both LOS as well as resource utilization. Our patient population included a wide variety of demographics from all gestational ages. A potential confounding factor in our analysis is that prematurity alone is a risk factor for increased morbidity and mortality and therefore could increase patient LOS regardless of surgical intervention. Although there are many factors that may contribute to both metrics, these data may help elucidate whether some outcomes can be anticipated and addressed to decrease both LOS and resource utilization.

The diagnosis of ventriculomegaly can be made on screening prenatal ultrasound (US), demonstrated by atrial dilation of >10 mm.^[14] Serial imaging with either repeat US and/or fetal magnetic resonance imaging is generally recommended for monitoring of progression. Prenatal diagnosis and serial monitoring of ventriculomegaly can aid in anticipation of NICU admission and postnatal surgical planning.^[14] In this way, prenatal diagnosis of CNS anomalies may lead to reduced NICU LOS.^[3] 40% of our study patients had prenatal diagnosis of hydrocephalus or another neurological anomaly and therefore were admitted to the NICU following delivery in anticipation of either VP shunt placement or advanced care management. Most patients with a prenatal diagnosis of CNS abnormality in our study had shorter LOS compared to postnatally diagnosed patients. Although infants born with a congenital anomaly or requiring a neurosurgical procedure are at increased risk for prolonged LOS, the patient population with prenatal diagnosis were more likely to have clinical courses without infections or shunt revisions. In 15 of our patients with prenatal diagnoses, the LOS was <20 days. The difference in LOS between these groups might have been due to one of several factors. One possibility is that those with prenatal diagnoses had different pathologies with different inherent complication rates or illness severity. For example, IVH is typically diagnosed postnatally as a sequela of prematurity. Infants with IVH also have the potential for higher complication rates depending on the degree of bleed. Another potential possibility is that cases with known prenatal diagnoses have post-delivery care plans created by multiple sub-specialists and the families prior to birth, which also increases awareness of these cases. This is an area for future research as prenatal diagnoses continue to increase as the medical field evolves.

Prior studies have demonstrated that rates of shunt infection for patients that undergo VP shunt placement are between 10% and 14% in neonates.^[9,11] In our study population, rate of infection was 11% ($n = 7$), and of those infections a majority ($n = 5$) occurred within the first 14 days following shunt procedure. We demonstrated that patients in this population who had an

infection complicating shunt placement had longer average LOS by an average of 9 days compared to patients who did not develop infection. For our neurosurgical patients, average LOS was 59 days with infection increasing this time frame to 67 days. Although the duration of the study ranged from January 1, 2010, to April 30, 2021, data on average LOS across all NICU patients in our institution were only available from October 2018 to April 2021. During this time frame, the average LOS was 22 days. LOS in the NICU may depend on a variety of factors, including multiple different pathologies as well as sequelae of prematurity alone. Patients who undergo neurosurgical procedures during their NICU admission may have a longer LOS at baseline and may have increased risk for complications such as infection which can further delay discharge. Implementation of clinical care guidelines or protocols for reduction of shunt infection following VP shunt placement has previously been examined, though any reduction in infection demonstrated in this study did not achieve clinical significance.^[6] In prior investigations, CGA at time of shunt placement was identified as a risk factor for infection with a significant difference between shunt placement at 26 weeks versus 33 weeks of gestation.^[2] Average CGA at time of VP shunt placement for our study was approximately 38 weeks. Further investigation into timing of infections and perioperative protocols may inform infection prevention practices and ultimately decrease both LOS and resource utilization.

Timing of shunt placement is complex for each patient's unique circumstance. Prior studies have shown that the relative risk for infection is higher in late shunt placement versus early shunt placement. In patients with late shunt placement, there were increased cases of CSF leakage which was thought to be due to progressive hydrocephalus leading to wound bulging and subsequent CSF leakage thus leading to higher rates of infection.^[13] Earlier shunt intervention could potentially avoid the CSF leakage that occurs during period of watchful waiting which would reduce infection rates in this population. Continuing inter-disciplinary team discussions with the family to provide optimal timing of surgery can help to decrease rates of infection and thus decrease LOS.

Previous studies examining overall cost-effectiveness of different interventions for hydrocephalus demonstrated that VP shunt placement was more clinically and cost-effective when compared to endoscopic third ventriculostomy (ETV) or ETV with choroid plexus cauterization.^[9] Average daily cost per patient for our study population, which evaluated VP shunt and subgaleal shunt placement, was higher than average daily NICU cost. Further research is needed on how specific interventions contribute to cost of admission.

Limitations

There were several potential limitations of our study. First, it was a single-center study, and analysis of readmission and ED

visits was limited to review institutional EMR. The study also was not an age matched control study. Consistent definitions and costing methodology utilized have been the same since 2015 and thus adjustments for inflation were not performed. The cost of surgery is multi-factorial due to additional costs associated with each procedure (e.g., anesthesia) and the report from the financial data mart did not delineate this information, as each case had different contributing factors.

CONCLUSION

Neonates who underwent neurosurgical procedures during initial NICU hospitalization had increased LOS and health-care utilization costs compared to average neonates during the study period. Further research is needed to optimize health-care utilization for these high-risk neonates along with studying other pathologies and LOS. The importance of such efforts has only been further emphasized by the recent COVID-19 pandemic, which has brought to light the need for cost-effective care and resource optimization. Increased efforts in prenatal testing of CNS abnormalities as well as individual neurologic pathologies could also be of great advantage due to potential planning for these patients which as a result could help guide care.

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Declaration of patient consent

Patient's consent not required as patient's identity is not disclosed or compromised.

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Conflicts of interest

There are no conflicts of interest.

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