JNS PEDIATRICS

CLINICAL ARTICLE

J Neurosurg Pediatr 17:260–269, 2016

Trends in hospitalization of preterm infants with intraventricular hemorrhage and hydrocephalus in the United States, 2000–2010

Eisha A. Christian, MD,[1] Diana L. Jin, BA,[1] Frank Attenello, MD,[1] Timothy Wen, MPH,[1] Steven Cen, PhD,[1] William J. Mack, MD,[1] Mark D. Krieger, MD,[1,2] and J. Gordon McComb, MD[1,2]

[1]Department of Neurosurgery, Keck School of Medicine of USC, University of Southern California, Los Angeles; and [2]Division of Neurosurgery, Children's Hospital Los Angeles, California

OBJECTIVE Even with improved prenatal and neonatal care, intraventricular hemorrhage (IVH) occurs in approximately 25%–30% of preterm infants, with a subset of these patients developing hydrocephalus. This study was undertaken to describe current trends in hospitalization of preterm infants with posthemorrhagic hydrocephalus (PHH) using the Nationwide Inpatient Sample (NIS) and the Kids' Inpatient Database (KID).

METHODS The KID and NIS were combined to generate data for the years 2000–2010. All neonatal discharges with ICD-9-CM codes for preterm birth with IVH alone or with IVH and hydrocephalus were included.

RESULTS There were 147,823 preterm neonates with IVH, and 9% of this group developed hydrocephalus during the same admission. Of patients with Grade 3 and 4 IVH, 25% and 28%, respectively, developed hydrocephalus in comparison with 1% and 4% of patients with Grade 1 and 2 IVH, respectively. Thirty-eight percent of patients with PHH had permanent ventricular shunts inserted. Mortality rates were 4%, 10%, 18%, and 40%, respectively, for Grade 1, 2, 3, and 4 IVH during initial hospitalization. Length of stay has been trending upward for both groups of IVH (49 days in 2000, 56 days in 2010) and PHH (59 days in 2000, 70 days in 2010). The average hospital cost per patient (adjusted for inflation) has also increased, from $201,578 to $353,554 (for IVH) and $260,077 to $495,697 (for PHH) over 11 years.

CONCLUSIONS The number of neonates admitted with IVH has increased despite a decrease in the number of preterm births. Rates of hydrocephalus and mortality correlated closely with IVH grade. The incidence of hydrocephalus in preterm infants with IVH remained stable between 8% and 10%. Over an 11-year period, there was a progressive increase in hospital cost and length of stay for preterm neonates with IVH and PHH that may be explained by a concurrent increase in the proportion of patients with congenital cardiac anomalies.

http://thejns.org/doi/abs/10.3171/2015.7.PEDS15140

KEY WORDS intraventricular hemorrhage; posthemorrhagic hydrocephalus; Nationwide Inpatient Sample; Kids' Inpatient Database; preterm neonates; preterm infants

Intraventricular hemorrhage (IVH) is a significant morbidity of preterm low birth weight (LBW) infants, leading to multiple complications, including posthemorrhagic hydrocephalus (PHH) and periventricular hemorrhagic infarction.[2,37] Treatment of this patient population is complex because of multisystem comorbidities requiring multiple subspecialists, and prognosis is impacted by many factors, including gestational age, birthweight, and additional complications of prematurity. Intervention for neonates with a gestational age of less than 22 weeks is typically not recommended, but the American Academy of Pediatrics recommends an individualized treatment algorithm based on patient input combined with current morbidity and outcomes data.[35] Given that treatment decisions are based on the most up-to-date information, there is a need to identify the most recent incidence and outcomes data in preterm infants with IVH and PHH.

The previously reported incidence of IVH in preterm infants with very low birth weight (VLBW; < 1500 g) decreased from 50% in the early 1980s to around 20% in 2005, because of advances in both prenatal and neonatal care.[34] Despite the decreased rate of IVH, however, im-

ABBREVIATIONS CDC = Centers for Disease Control and Prevention; HCUP = Healthcare Cost and Utilization Project; ICD-9-CM = *International Classification of Diseases, Ninth Revision, Clinical Modification*; IVH = intraventricular hemorrhage; KID = Kids' Inpatient Database; LBW = low birth weight; LOS = length of stay; NEC = necrotizing enterocolitis; NIS = Nationwide Inpatient Sample; PHH = posthemorrhagic hydrocephalus; VLBW = very LBW.

SUBMITTED March 9, 2015. **ACCEPTED** July 6, 2015.
INCLUDE WHEN CITING Published online November 6, 2015; DOI: 10.3171/2015.7.PEDS15140.

proved survival of premature infants has resulted in a larger at-risk IVH population.[2,7,9,32] In addition, IVH admissions seem to vary by region and hospital: St. Louis Children's Hospital, St. Louis, Missouri, reported increasing numbers,[15] while Rainbow Babies and Children's Hospital in Cleveland, Ohio, reported a 3-fold drop in admissions over the last decade.[34]

The national rates of IVH in premature infants in the United States have not previously been evaluated by any study, to our knowledge. We have used the Nationwide Inpatient Sample (NIS) and the Kids' Inpatient Database (KID), respectively corresponding to a 20% and 80% stratified sample of US inpatient discharges over the last 11 years (2000–2010), to evaluate hospital trends of preterm infants with IVH and PHH. Additional outcomes of interest in this population include mortality rates, neonatal comorbidities and complications, length of stay (LOS), and hospitalization costs, in addition to the incidence of hydrocephalus and its treatment with CSF diversion.

Methods

Data Source

The NIS and KID together compose the largest, public, all-payer, inpatient care dataset in the United States (https://www.hcup-us.ahrq.gov/databases.jsp). As part of the Healthcare Cost and Utilization Project (HCUP), the NIS and KID have longitudinal hospital inpatient discharge data from more than 1000 hospitals, with the NIS representing 20% of all hospital discharges and KID representing 80% of pediatric discharges in the United States. Discharge data were available for the years 2000, 2003, 2006, and 2009 in the KID dataset. The remaining years (2001, 2002, 2004, 2005, 2007, 2008, and 2010) were captured with the NIS, and there was no overlap between the 2 datasets. To extrapolate national estimates, weights were applied as indicated in the HCUP-NIS guide to calculating NIS variances.[10]

Study Population

Admissions were identified using the ICD-9-CM codes for patients with a preterm birth weight (ICD-9-CM Codes 765.00–765.29) and IVH grade (Codes 772.10–772.14). Patients with multiple IVH grades were assigned the highest grade listed. Further classification within the IVH population included the presence of a hydrocephalus diagnosis (Codes 742.3, 331.3, 331.4).

Outcomes of interest were mortality, temporary CSF diversion procedures (ICD-9-CM Codes 2.20–2.22), and placement of a permanent CSF-diverting shunt (Codes 2.30–2.35, 2.39). Shunt complications of interest included replacement of a shunt (Code 2.42), mechanical implant complication (Code 996.2), implant infection (Code 996.63), and other implant complication (Code 996.75).

Additional complications and comorbidities of interest included seizures (ICD-9-CM Code 779.0); necrotizing enterocolitis (Codes 777.5–777.53); intestinal perforation (Code 777.6); pulmonary complications (mechanical ventilation, Code 96.71, 96.72; respiratory support, Codes 93.90–96.72; respiratory distress, Codes 769, 770.6–770.8, 770.89); hematological complications (disseminated intravascular coagulation, Code 776.2; jaundice, Codes 774.2, 774.6; hematological disorder, Codes 776.0–776.9); presumed sepsis (Codes V29.0, 771.8, 771.81, 771.83, 771.89); endocrine complications (Codes 775.1–775.9); and congenital heart defects (Codes 745.0–747.9).

Unlike KID, the NIS did not classify hospitals based on the National Association of Children's Hospitals and Related Institutions, so hospitals were identified with their hospital identification number and were assigned a classification based on what their KID designation was for the previous available KID year dataset. In addition, regions (South, Northeast, West, and Midwest) were based on the definitions by the US Census Bureau (www.census.gov).

To prevent double counting, initial hospitalization of neonates that resulted in a discharge to another acute care facility (pretransfer hospitalizations) were excluded from the study.[3] Age of admission was further limited to less than 3 months to exclude readmissions.

Discrete patient predictors, including race, sex, weight, gestational age, and IVH grade, were encoded as categorical variables in NIS and KID. Hospital-level variables such as hospital region were also included as categorical variables. Total charges were adjusted to 2013 dollars to account for inflation using the consumer price index provided by the US Department of Labor with the aid of an inflation calculator (http://www.usinflationcalculator.com/).

Statistical Analysis

The primary goal was to describe the national trends in hospitalization of neonates with IVH and PHH. The sampling effects were taken into account by applying NIS survey weight using "surveymean" and "sureveyfreq" procedures. Estimates of the national average (mean and rate) and corresponding standard error were based on the HCUP data analysis guidelines.[10] The α-level was set to 0.05. All analyses were performed using SAS version 9.4 (SAS Institute).

Results

Patient Characteristics

From 2000 through 2010, 147,823 preterm neonates with IVH were admitted. Table 1 provides data on sex, gestational age, birth weight, and racial characteristics of newborn preterm infants with a diagnosis of IVH. Fifty-six percent were male infants. Gestational age ranges were was broken down according to ICD-9-CM coding and are listed in Table 1. Birth weight was missing in 3% of the patient population; 41% of preterm neonates with IVH had a birth weight between 500 and 999 g. The largest racial group consisted of white infants (34%), followed by black infants (19%) and Hispanic infants (15%); 23.5% of patients did not have race listed.

Table 2 reports IVH grade according to Papile et al.[31] Forty-three percent of hemorrhages were classified as Grade 1, 18% as Grade 2, 13% as Grade 3, and 14% as Grade 4; 12% were coded for IVH with no specific grade listed.

Nine percent of preterm infants with IVH developed hydrocephalus during their initial admission. Table 3 re-

TABLE 1. Characteristics of preterm infants with IVH (n = 147,823)

Characteristics	No. of Patients	% of Patients	95% CI
Sex			
M	82,858	56	55.4–56.7
F	64,936	44	43.3–44.5
Unknown	29	<1	—
Gestational age, wks			
<24	5,909	4	3.7–4.3
24	10,082	7	6.3–7.25
25–26	19,696	13	12.7–14.0
27–28	18,359	12	11.9–13.0
29–30	18,043	12	11.7–12.7
31–32	17,133	12	11–12.2
33–34	8,868	6	5.5–6.5
35–36	3,856	3	2.4–2.8
Unknown	45,877	31	28.9–33.1
Birth weight, g			
<500	3,016	2	1.9–2.2
500–749	30,167	20	19.7–21.1
750–999	30,844	21	20.3–21.4
1,000–1,249	23,272	16	15.3–16.2
1,250–1,499	19,756	13	13.0–13.8
1,500–1,749	14,215	10	9.2–10.0
1,750–1,999	9,654	6	6–6.9
2,000–2,499	8,829	6	5.6–6.4
≥2,500	3,794	3	2.3–2.8
Unknown	4,276	3	2.61–3.18
Race			
White	50,102	34	31.6–36.2
Black	28,297	19	17.3–21.0
Hispanic	22,618	15	13.6–17.0
Asian/Pacific	3,802	3	1.8–3.3
Native American	808	0.5	0.4–0.7
Other	7,476	5	4.3–5.8
Unknown	34,720	23.5	19.9–27.0

ports the number of patients who developed hydrocephalus within each IVH grade. In 25% and 28% of patients with Grade 3 and 4 IVH, respectively, hydrocephalus developed, compared with 1% and 4% of patients with Grade 1 and 2 IVH, respectively.

Mortality rates (Table 4) also correlated with IVH grade. Forty percent of patients with Grade 4 IVH died during their initial admission, whereas patients with Grade 1, 2, and 3 IVH had mortality rates of 4%, 10%, and 18%, respectively.

Regional analysis revealed that the South had 42% of IVH admissions, followed by 21% in the West, 17% in the Northeast, and 20% in the Midwest (Fig. 1) (www.census.gov).

Payer status was also available: 51% percent of patients used Medicaid and 43% had private insurance. The remaining patients (6%) were either self-pay, no charge, or of unknown payer status.

TABLE 2. IVH grade

IVH Grade	No. of Patients (%)	95% CI
1	63,546 (43)	41.5–44.4
2	26,017 (18)	16.5–18.7
3	19,320 (13)	12.4–13.7
4	20,390 (14)	13.2–14.4
Unspecified	18,550 (12)	11.1–14.0

TABLE 3. Preterm infants with IVH and PHH

IVH Grade	No. of Patients	% w/ HCP	95% CI
1	549	1	0.7–1.0
2	1,127	4	3.7–5.0
3	4,890	25	23.4–27.2
4	5,651	28	25.8–29.6
Unspecified	1,518	8	7.2–9.2
Total	13,736	9	8.6–10.0

HCP = hydrocephalus.

Neonatal Comorbidities and Complications

Neonatal comorbidities were identified (Table 5). Six percent of patients with IVH had seizures during their initial admission, and 38% had congenital heart defects. Eight percent had necrotizing enterocolitis (NEC) and 4% had intestinal perforation. Eighty-five percent had pulmonary complications with respiratory distress, requiring mechanical ventilation or additional respiratory support. Sixty-eight percent had hematological complications, including disseminated intravascular coagulation and neonatal jaundice. Of note, the proportion of hematological complications decreased with IVH grade (i.e., 75% of patients with Grade 1 IVH had hematological comorbidities vs 56% of patients with Grade 4 IVH). Fifty percent of patients underwent a sepsis evaluation during their initial hospitalization. Three percent of patients had periventricular leukomalacia.

CSF Diversion Procedures

Table 6 reports the number of patients with IVH who received either temporary or permanent CSF diversion. Three percent of patients with IVH received temporary CSF diversion: 7% and 11% of patients with Grade 3 and 4 IVH, respectively, received temporary CSF diversion; 9% and 12%, respectively, received permanent shunts. A total

TABLE 4. Mortality rates

Variable	No. of Patients	Mortality Rate (%)	95% CI
IVH Grade			
1	2,264	4	3.2–4
2	2,537	10	9.0–10.5
3	3,539	18	16.8–19.9
4	8,236	40	38.7–42.0
Unspecified	2,706	15	13.1–16.1
Overall IVH	19,283	13	12.4–13.7
Overall PHH	1,456	11	9.5–11.7

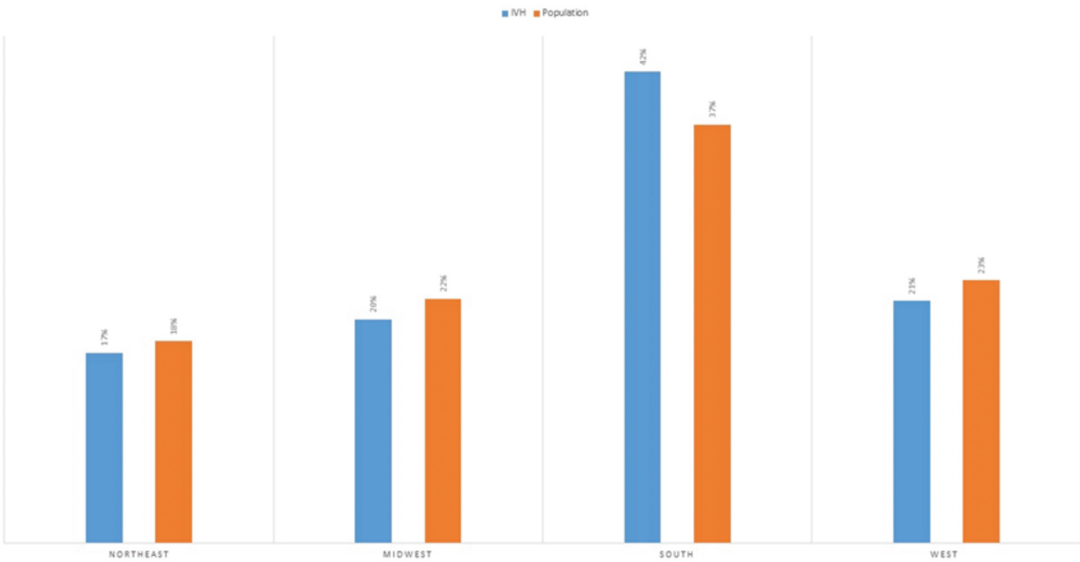

FIG. 1. Regional distribution of preterm infants with IVH versus the US population. Figure is available in color online only.

of 5266 patients (38% of patients with PHH) had permanent shunts inserted; the remaining either died or did not require further CSF diversion during this admission.

Shunt complications (Table 7) were also identified by ICD-9-CM codes. Shunt replacement occurred 696 times (13%): 8% were diagnosed with a mechanical implant complication and 7% with an implant infection during initial hospitalization. Overall shunt complications increased when gestational age was less than 24 weeks (relative risk [RR] 1.85; p < 0.01).

Yearly Trends

Figure 2A and B portray annual admissions for preterm infants with IVH and PHH. There was an increase in IVH admissions between 2002 and 2004, after which admissions fluctuated in frequency. The percentage of patients who developed hydrocephalus remained relatively constant between 8% and 10% annually (Fig. 2C). Annual trends in complications and comorbidities were also identified (Fig. 3). The proportion of congenital heart defects in our study population had a noticeable increase from 27% in 2000 to 53% in 2010. Rates of NEC and sepsis also increased over the study interval, but pulmonary complications decreased from 92% to 83%.

Birth weight (Fig. 4A) and gestational age (Fig. 4B) in our patient population were also included in our trend

TABLE 5. Overall complications and comorbidities stratified by IVH grade*

Complication	Grade 1	Grade 2	Grade 3	Grade 4	Overall %
Seizures	2 (1.5–2.3)	5 (4.0–5.3)	10 (8.4–10.6)	17 (15.8–19.08)	6 (5.5–6.7)
Pulmonary	82 (80.6–82.6)	87 (85.8–87.9)	87 (85.7–88.3)	89 (87.5–89.5)	85 (84.7–86.2)
NEC	7 (6.2–7.4)	9 (8.5–10.3)	10 (8.6–10.5)	11 (9.6–11.6)	8 (7.5–8.6)
Intestinal perforation	2 (1.6–2.1)	4 (3.1–4.2)	6 (4.8–6.5)	7 (5.8–7.5)	4 (3.1–4)
Hematological complications	75 (73.2–75.8)	68 (65.6–69.3)	59 (56.6–61.2)	56 (53.8–58.2)	68 (66.6–69.2)
Endocrine complications	35 (33.4–36.7)	43 (41.1–45.4)	41 (38.9–43.5)	48 (45.3–49.7)	39 (37.2–40.4)
Congenital heart defects	35 (33.1–36.5)	45 (42.9–47.3)	44 (41.5–45.9)	45 (42.4–47.1)	38 (36.6–39.8)
Periventricular leukomalacia	2 (1.5–2.0)	3 (2.5–3.3)	5 (4–5.3)	9 (8.1–10.1)	3 (2.8–3.4)

* Data given as the percentage of patients with the 95% CI in parentheses.

TABLE 6. Number of patients requiring a CSF-diverting procedure stratified by IVH grade*

Type of CSF Diversion	Grade 1	Grade 2	Grade 3	Grade 4	IVH NOS	Total
Temporary	67 (<1)	149 (<1)	1,399 (7)	2,191 (11)	495 (3)	4,302 (3)
Permanent	110 (<1)	226 (<1)	1,712 (9)	2,481 (12)	737 (4)	5,266 (4)

NOS = not otherwise specified.
* Data are presented as the number (%) of patients.

TABLE 7. Summary of shunt-related complications

Shunt Complication*	No. of Patients (%)	95% CI
Shunt replacement	696 (13)	11.1–15.4
Mechanical implant complications	415 (8)	6.2–9.6
Implant infection	346 (7)	5–8.1

* Based on those who received a permanent shunt (n = 5266).

analysis. Both variables remained stable over time with the exception that gestational age was not coded prior to 2003. The proportion of high-grade (Grade 3/4) IVH trended down over 11 years (Fig. 4C).

Population Trends

We also used the Centers for Disease Control and Pre-

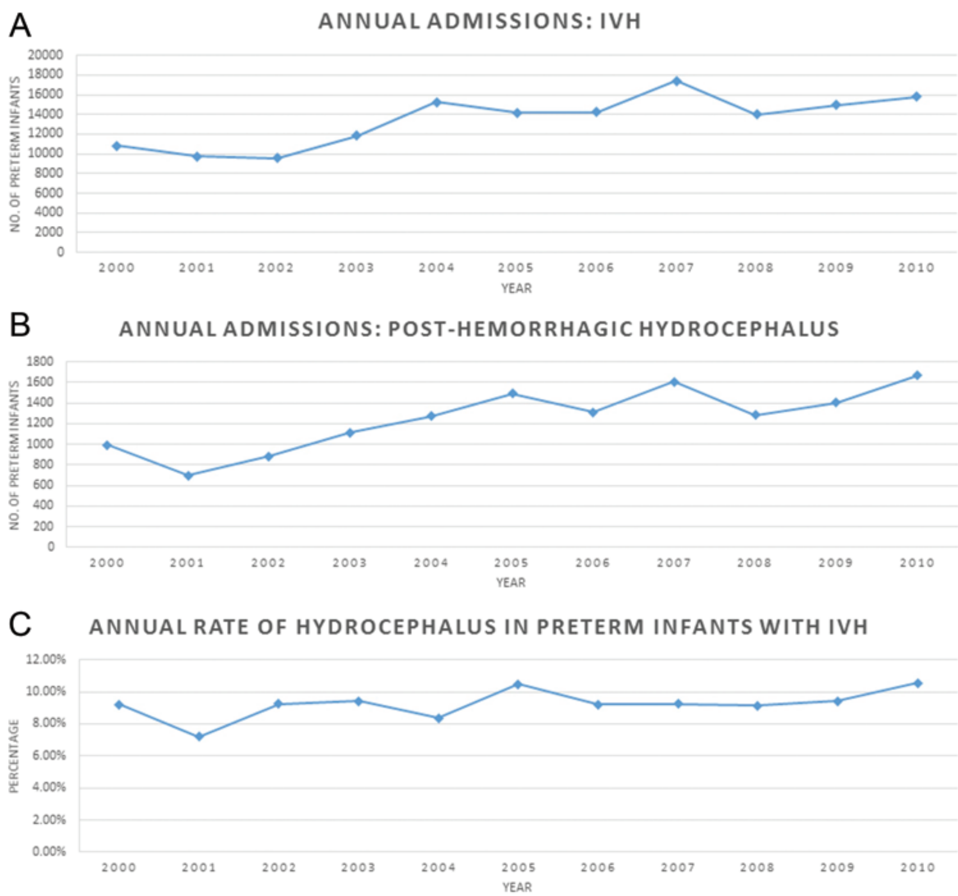

FIG. 2. Trends in annual admissions of preterm infants with IVH and PHH, and annual rate of hydrocephalus development in preterm infants with IVH. **A:** Annual admissions of preterm infants with IVH. **B:** Annual admission of preterm infants with PHH. **C:** Annual percentage of preterm infants with IVH who develop hydrocephalus. Figure is available in color online only.

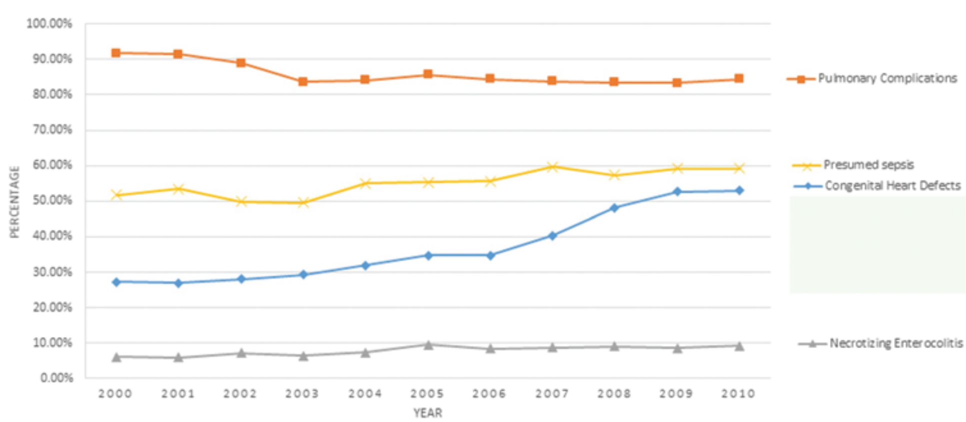

FIG. 3. Graph of annual rate of neonatal comorbidities. Figure is available in color online only.

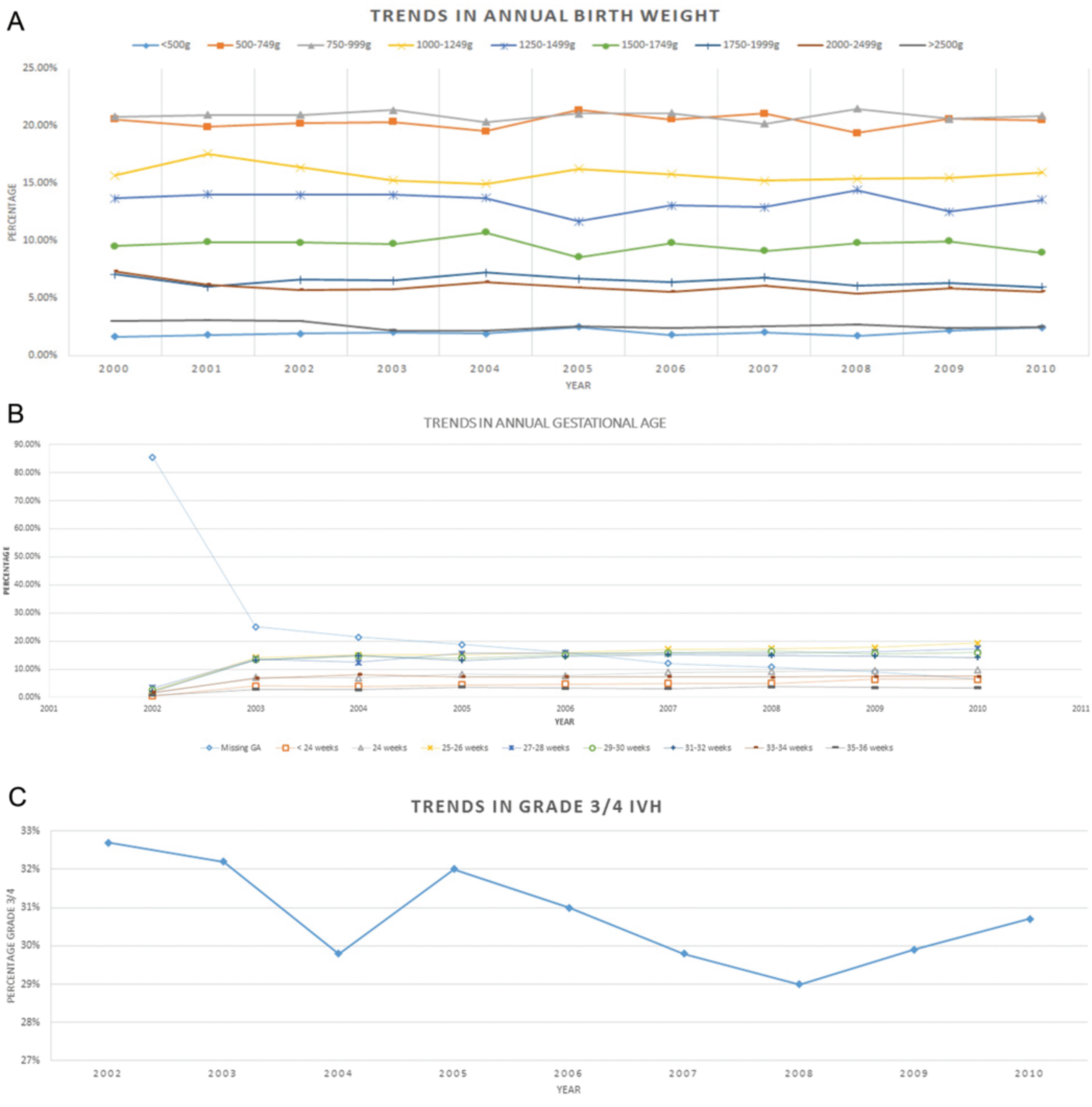

FIG. 4. Trends in annual birth weight, gestational age, and Grade 3/4 IVH in preterm infants with IVH. **A:** Trends in annual birth weight in preterm infants with IVH. **B:** Trends in gestational age (GA) in preterm infants with IVH. **C:** Trends in high-grade (Grade 3/4) IVH. Figure is available in color online only.

vention (CDC) publications on annual birth[16–26] and death rates[1,8,11–14,27–30,39] to determine trends in the number and rate of preterm births, in addition to infants with low birth weight (LBW; < 2500 g) or very LBW (VLBW) over the same time (Fig. 5A and B). The number and rate of preterm births trended down over the course of 11 years. In addition, the preterm mortality rate (Fig. 5C) trended up between 2000 and 2003, after which it decreased to 104 deaths per 1000 live births. LBW rates increased mildly from 7.6% to 8.2%, and VLBW rates remained stable over 11 years.

Length of Stay and Hospital Costs

The average length of stay (LOS) over 11 years was 53 days for the IVH group and 62 days for the PHH group. LOS (Fig. 6) has been trending upward for patients with IVH (49 days in 2000, 56 days in 2010) and PHH (59 days in 2000, 70 days in 2010). The average hospital cost per

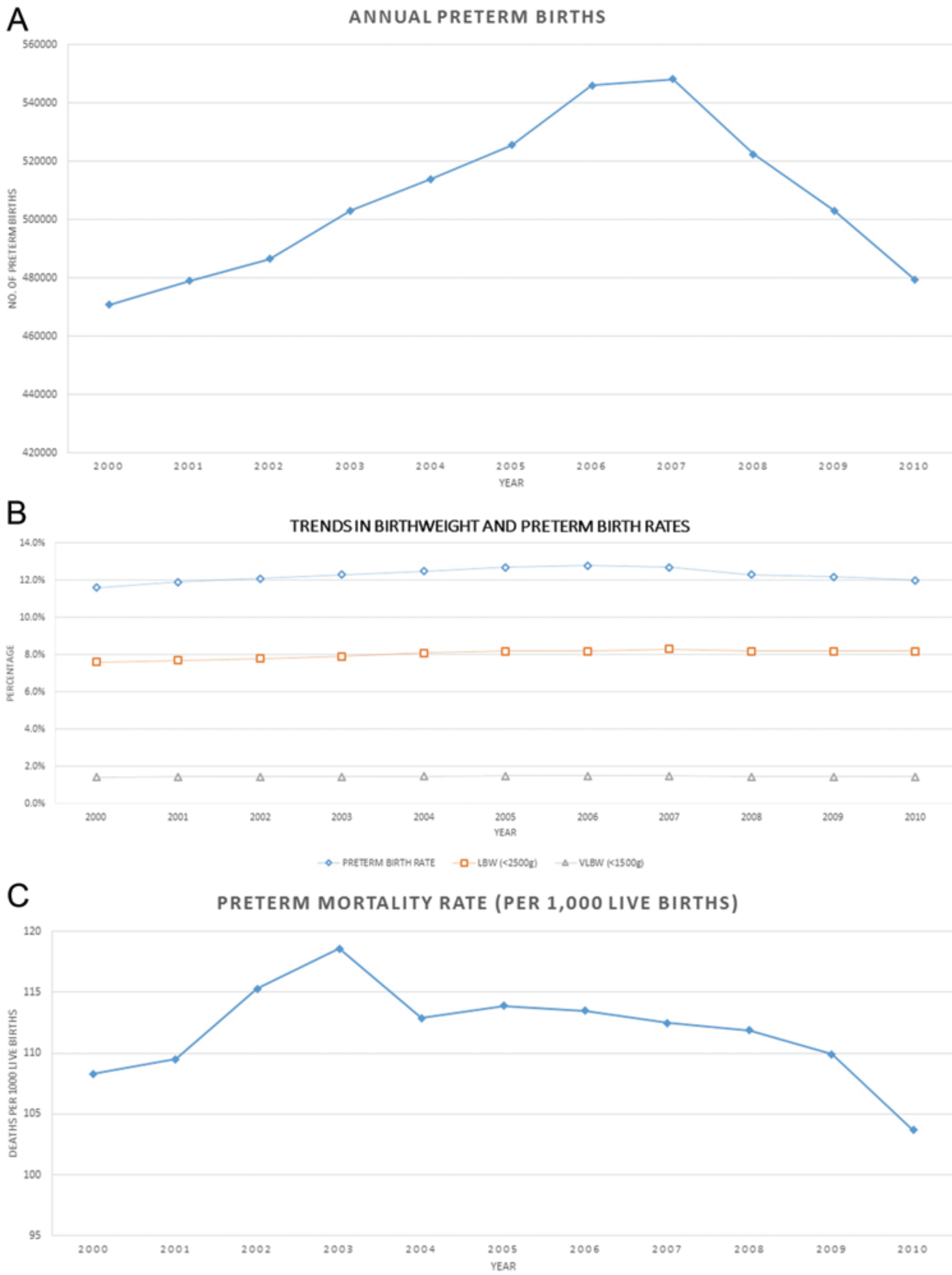

FIG. 5. Trends in annual number of preterm births, birth weight and preterm birth rates, and preterm mortality rates. **A:** Annual number of preterm births. **B:** Overall population trends in LBW, VLBW, and preterm birth rates. **C:** Preterm infant mortality rate (per 1000 live births). Figure is available in color online only.

patient (adjusted for inflation) has also increased, from $201,578 to $353,554 for patients with IVH, and $260,077 to $495,697 for those with PHH, over 11 years (Fig. 7A). To account for increasing LOS, average daily costs were also calculated: In 2000, the average daily cost for a preterm infant with IVH was $4941; it increased to $8362 in 2010 (Fig. 7B).

Discussion

IVH remains a major complication of prematurity. The acute and long-term care of these patients is complex, given the multiple comorbidities; and single-center studies are often limited, given the small number of patients who are treated at individual hospitals. There have been multiple conflicting reports on the incidence of hydrocephalus in this group,[15,34] with some centers citing an increase and others a decrease. Therefore, we used the NIS and KID to look at 11 years of HCUP data on more than 147,000 preterm infants with IVH.

Population Trends

The number of patients admitted with IVH has in-

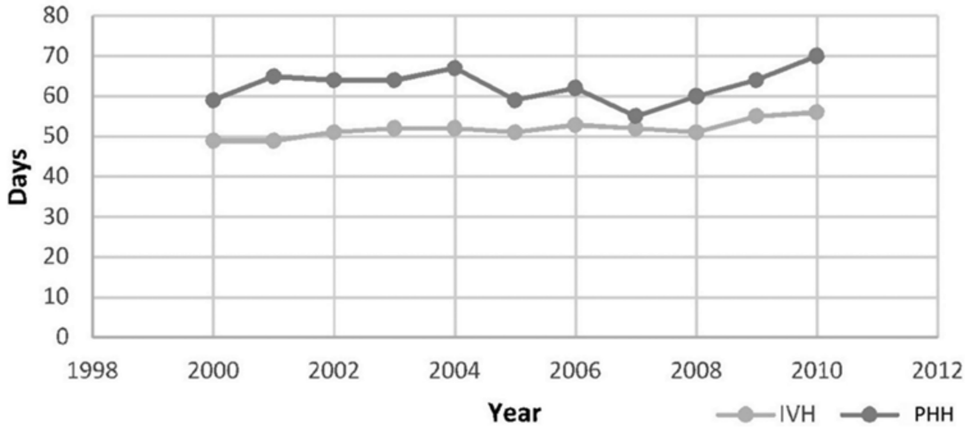

FIG. 6. Average length of stay (in days) per patient.

creased between 2000 and 2010 (Fig. 2A). In contrast, the rate and overall number of preterm births have decreased since 2000[16–26] (Fig. 5A). In addition, the overall percentage of VLBW infants (< 1500 g) has remained stable (Fig. 5B), and the rates of preterm infants with gestational ages less than 32 and 28 weeks have been decreasing, according to the CDC data.[16–18,20–26] This increase in the number of admissions for preterm neonates with IVH implies a recent increase in either the incidence of IVH in preterm births or survival of preterm infants who then develop IVH. Therefore, we used CDC data to trend mortality rate of preterm infants, which increased between 2000 and 2003 after which it decreased to 104 deaths per 1000 live births (Fig. 5C). This decrease in mortality rate corresponds to the increase in number of preterm admissions with IVH, giving further credence to the hypothesis that the improved survival of preterm infants is the reason for the increase in preterm neonates with IVH.

Fifty-six percent of our study population was male; this sex distribution correlated with our institutional findings at Children's Hospital Los Angeles (64% boys) and recent work published by Primary Children's Hospital in Salt Lake City, Utah (65% boys).[36] However, researchers at Johns Hopkins University recently published their institutional experience with posthemorrhagic hydrocephalus and reported a 47% male distribution.[38]

A regional breakdown revealed that the South had 42% of IVH admissions (37% US population per US Census

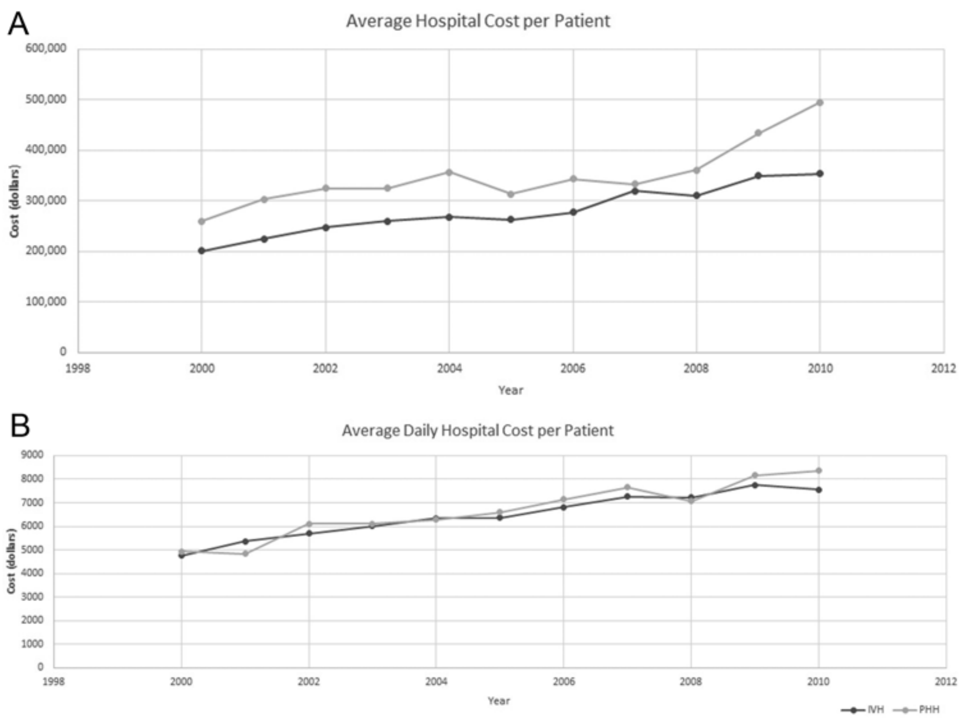

FIG. 7. Trends in hospital costs and daily hospital costs per patient. **A:** Average hospital cost per patient. **B:** Average daily hospital cost per patient.

Bureau), whereas the Northeast, Midwest, and West proportions were slightly lower than their population percentiles (Fig. 1). These numbers also correlate with the reported increased numbers of preterm births in Southern states.[16–26]

Neonatal Comorbidities and Complications

The leading diagnosis for a complicated newborn hospitalization is preterm birth with LBW;[5] it is also the second leading cause of death (after congenital malformations) in infants less than 1 year old. Preterm infants have multiple comorbidities, including congenital heart defects, and multiple complications, including underdeveloped lungs or NEC—all these factors contribute to worse outcomes and prolonged hospitalization. In our nationwide analysis, we found that 38% of preterm infants with IVH also have congenital heart defects. In addition, this proportion has doubled over the period of our study, which may account for the longer LOS and cost of hospitalization. Furthermore, 85% of our patient population required either additional respiratory support or mechanical ventilation, and greater than 50% required workup for sepsis. Given these complicating factors, this patient population requires expert care with multiple pediatric specialists.

We also found that approximately 9% of preterm infants with IVH develop hydrocephalus. This proportion was related to IVH grade, with 1% of patients with Grade 1 IVH developing hydrocephalus and 28% of patients with Grade 4 IVH developing the condition. Thirty-eight percent of preterm infants with PHH required a permanent shunt during their initial admission. The remaining patients either died or did not require further CSF diversion during their original admission; these numbers do not account for patients who develop delayed hydrocephalus and receive shunts on subsequent admission. In addition, our analysis showed that shunt complications were increased in patients with a gestational age of less than 24 weeks ($RR = 1.85$; $p < 0.01$).

Cost Analysis

In 1997, Pikus et al.[33] reported that the average cost for the first hospitalization of a preterm infant with PHH was $162,000, similar to other reports at the time. We report that the average cost of initial hospitalization has increased to $495,000 in 2010 from $260,000 in 2001, after adjusting for inflation. In addition, we also note that average LOS has increased over 11 years. To control for this increased LOS, we also analyzed average daily cost for a preterm infant with IVH, and found that it doubled in 11 years after controlling for inflation. The most notable change that accounts for the increase in LOS and cost was the increase in incidence of congenital cardiac anomalies in preterm infants with IVH, which increased from 27% in 2000 to 53% in 2010. We noted no change in birth weight over the 11-year period, and the trends in gestational age were not reliable, given that coding for gestational age did not begin until 2003.

Limitations

The main limitation in this study comes with the use of a large population-based administrative database. ICD-9-CM codes are entered by hospital staff with a wide variation in training and oversight. The potential for recording bias results in estimates of coding accuracy of approximately 80%.[4,6] This bias can affect not only coding of diagnoses but also covariates and complications. In addition, even though we used previously published methods of preventing double counting,[3] we cannot completely eliminate it, because of the lack of individual identifiers. Finally, these datasets only capture a single admission and, therefore, patients who develop delayed hydrocephalus on subsequent admission are not included in our analysis.

Conclusions

We evaluated 11 years of national data using the NIS and KID to review trends in hospital admission, mortality, and comorbidities of neonates with IVH and hydrocephalus. The number of admissions of preterm infants with IVH has increased despite a decrease in the number of preterm births; this increase corresponds to a decreased preterm mortality rate. The incidence of hydrocephalus in this population has remained stable, between 8% and 10%. Admission status is complicated by comorbidities such as congenital heart defects (38%) and requirement for respiratory support (85%). In addition, length of hospital stay has been increasing and the average daily cost has doubled in 11 years; these may be explained by the increased incidence of congenital cardiac anomalies. In conclusion, the treatment of preterm infants with IVH and hydrocephalus deserves continued attention, given the improved survival and increase in numbers and complexity of these patients.

References

1. Arias E, Anderson RN, Kung HC, Murphy SL, Kochanek KD: Deaths: final data for 2001. **Natl Vital Stat Rep 52:**1–115, 2003
2. Bassan H: Intracranial hemorrhage in the preterm infant: understanding it, preventing it. **Clin Perinatol 36:**737–762, v, 2009
3. Burke BL, Robbins JM, Bird TM, Hobbs CA, Nesmith C, Tilford JM: Trends in hospitalizations for neonatal jaundice and kernicterus in the United States, 1988–2005. **Pediatrics 123:**524–532, 2009
4. Burns EM, Rigby E, Mamidanna R, Bottle A, Aylin P, Ziprin P, et al: Systematic review of discharge coding accuracy. **J Public Health (Oxf) 34:**138–148, 2012
5. Fowler TT, Fairbrother G, Owens P, Garro N, Pellegrini C, Simpson L: Trends in complicated newborn hospital stays & costs, 2002-2009: implications for the future. **Medicare Medicaid Res Rev 4:**E1, 2014
6. Gologorsky Y, Knightly JJ, Lu Y, Chi JH, Groff MW: Improving discharge data fidelity for use in large administrative databases. **Neurosurg Focus 36(6):**E2, 2014
7. Hack M, Fanaroff AA: Outcomes of children of extremely low birthweight and gestational age in the 1990's. **Early Hum Dev 53:**193–218, 1999
8. Heron M, Hoyert DL, Murphy SL, Xu J, Kochanek KD, Tejada-Vera B: Deaths: final data for 2006. **Natl Vital Stat Rep 57:**1–134, 2009
9. Horbar JD, Badger GJ, Carpenter JH, Fanaroff AA, Kilpatrick S, LaCorte M, et al: Trends in mortality and morbidity for very low birth weight infants, 1991–1999. **Pediatrics 110:**143–151, 2002

10. Houchens R, Elixhauser A: **Final Report on Calculating Nationwide Inpatient Sample (NIS) Variances, 2001.** Rockville, MD: Agency for Healthcare Research and Quality, 2005
11. Hoyert DL, Heron MP, Murphy SL, Kung HC: Deaths: final data for 2003. **Natl Vital Stat Rep 54:**1–120, 2006
12. Kochanek KD, Murphy SL, Anderson RN, Scott C: Deaths: final data for 2002. **Natl Vital Stat Rep 53:**1–115, 2004
13. Kochanek KD, Xu J, Murphy SL, Miniño AM, Kung HC: Deaths: final data for 2009. **Natl Vital Stat Rep 60:**1–116, 2011
14. Kung HC, Hoyert DL, Xu J, Murphy SL: Deaths: final data for 2005. **Natl Vital Stat Rep 56:**1–120, 2008
15. Limbrick DD Jr, Mathur A, Johnston JM, Munro R, Sagar J, Inder T, et al: Neurosurgical treatment of progressive post-hemorrhagic ventricular dilation in preterm infants: a 10-year single-institution study. **J Neurosurg Pediatr 6:**224–230, 2010
16. Martin JA, Hamilton BE, Sutton PD, Ventura SJ, Mathews TJ, Kirmeyer S, et al: Births: final data for 2007. **Natl Vital Stat Rep 58:**1–85, 2010
17. Martin JA, Hamilton BE, Sutton PD, Ventura SJ, Mathews TJ, Osterman MJ: Births: final data for 2008. **Natl Vital Stat Rep 59:**1, 3–71, 2010
18. Martin JA, Hamilton BE, Sutton PD, Ventura SJ, Menacker F, Kirmeyer S: Births: final data for 2004. **Natl Vital Stat Rep 55:**1–101, 2006
19. Martin JA, Hamilton BE, Sutton PD, Ventura SJ, Menacker F, Kirmeyer S, et al: Births: final data for 2006. **Natl Vital Stat Rep 57:**1–104, 2009
20. Martin JA, Hamilton BE, Sutton PD, Ventura SJ, Menacker F, Kirmeyer S, et al: Births: final data for 2005. **Natl Vital Stat Rep 56:**1–103, 2007
21. Martin JA, Hamilton BE, Sutton PD, Ventura SJ, Menacker F, Munson ML: Births: final data for 2002. **Natl Vital Stat Rep 52:**1–113, 2003
22. Martin JA, Hamilton BE, Sutton PD, Ventura SJ, Menacker F, Munson ML: Births: final data for 2003. **Natl Vital Stat Rep 54:**1–116, 2005
23. Martin JA, Hamilton BE, Ventura SJ, Menacker F, Park MM: Births: final data for 2000. **Natl Vital Stat Rep 50:**1–101, 2002
24. Martin JA, Hamilton BE, Ventura SJ, Menacker F, Park MM, Sutton PD: Births: final data for 2001. **Natl Vital Stat Rep 51:**1–102, 2002
25. Martin JA, Hamilton BE, Ventura SJ, Osterman MJ, Kirmeyer S, Mathews TJ, et al: Births: final data for 2009. **Natl Vital Stat Rep 60:**1–70, 2011
26. Martin JA, Hamilton BE, Ventura SJ, Osterman MJ, Wilson EC, Mathews TJ: Births: final data for 2010. **Natl Vital Stat Rep 61:**1–72, 2012
27. Miniño AM, Arias E, Kochanek KD, Murphy SL, Smith BL: Deaths: final data for 2000. **Natl Vital Stat Rep 50:**1–119, 2002
28. Miniño AM, Heron MP, Murphy SL, Kochanek KD: Deaths: final data for 2004. **Natl Vital Stat Rep 55:**1–119, 2007
29. Miniño AM, Murphy SL, Xu J, Kochanek KD: Deaths: final data for 2008. **Natl Vital Stat Rep 59:**1–126, 2011
30. Murphy SL, Xu J, Kochanek KD: Deaths: final data for 2010. **Natl Vital Stat Rep 61:**1–117, 2013
31. Papile LA, Burstein J, Burstein R, Koffler H: Incidence and evolution of subependymal and intraventricular hemorrhage: a study of infants with birth weights less than 1,500 gm. **J Pediatr 92:**529–534, 1978
32. Philip AG, Allan WC, Tito AM, Wheeler LR: Intraventricular hemorrhage in preterm infants: declining incidence in the 1980s. **Pediatrics 84:**797–801, 1989
33. Pikus HJ, Levy ML, Gans W, Mendel E, McComb JG: Outcome, cost analysis, and long-term follow-up in preterm infants with massive grade IV germinal matrix hemorrhage and progressive hydrocephalus. **Neurosurgery 40:**983–989, 1997
34. Robinson S: Neonatal posthemorrhagic hydrocephalus from prematurity: pathophysiology and current treatment concepts. **J Neurosurg Pediatr 9:**242–258, 2012
35. Rysavy MA, Li L, Bell EF, Das A, Hintz SR, Stoll BJ, et al: Between-hospital variation in treatment and outcomes in extremely preterm infants. **N Engl J Med 372:**1801–1811, 2015
36. Spader HS, Hertzler DA, Kestle JR, Riva-Cambrin J: Risk factors for infection and the effect of an institutional shunt protocol on the incidence of ventricular access device infections in preterm infants. **J Neurosurg Pediatr 15:**156–160, 2015
37. Volpe JJ: Intracranial hemorrhage: germinal matrix-intraventricular hemorrhage, in Volpe JJ (ed): **Neurology of the Newborn.** Philadelphia: Saunders Elsevier, 2008, pp 517–588
38. Wang JY, Amin AG, Jallo GI, Ahn ES: Ventricular reservoir versus ventriculosubgaleal shunt for posthemorrhagic hydrocephalus in preterm infants: infection risks and ventriculoperitoneal shunt rate. **J Neurosurg Pediatr 14:**447–454, 2014
39. Xu J, Kochanek KD, Murphy SL, Tejada-Vera B: Deaths: final data for 2007. **Natl Vital Stat Rep 58:**1–19, 2010

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Christian. Acquisition of data: Jin. Analysis and interpretation of data: Christian, Jin, Attenello, Wen. Drafting the article: Christian, Jin. Critically revising the article: Christian, Attenello, Mack, Krieger, McComb. Reviewed submitted version of manuscript: Christian, Attenello, Mack, McComb. Approved the final version of the manuscript on behalf of all authors: Christian. Statistical analysis: Jin, Wen, Cen. Study supervision: Christian, Cen, Mack, McComb.

Correspondence

Eisha Christian, Department of Neurosurgery, Keck School of Medicine of USC, University of Southern California, 1200 N. State St., Ste. 3300, Los Angeles, CA 90033. email: echristi@usc.edu.