Published in final edited form as:

J Neurosurg Pediatr. 2012 May ; 9(5): 473–481. doi:10.3171/2012.1.PEDS11292.

Center effect and other factors influencing temporization and shunting of cerebrospinal fluid in preterm infants with intraventricular hemorrhage

Jay Riva-Cambrin, M.D., M.Sc.¹, Chevis N. Shannon, M.B.A., Dr.P.H.², Richard Holubkov, Ph.D.³, William E. Whitehead, M.D.⁴, Abhaya V. Kulkarni, M.D., Ph.D.⁵, James Drake, M.B.B.Ch., M.Sc.⁵, Tamara D. Simon, M.D., M.S.P.H.⁶, Samuel R. Browd, M.D., Ph.D.⁷, John R. W. Kestle, M.D.¹, and John C. Wellons III, M.D.² for the Hydrocephalus Clinical Research Network

¹Division of Pediatric Neurosurgery, Department of Neurosurgery, Primary Children's Hospital, University of Utah, Salt Lake City, Utah

²Section of Pediatric Neurosurgery, Division of Neurosurgery, Children's Hospital of Alabama, University of Alabama Birmingham, Alabama

³Department of Pediatrics, University of Utah, Salt Lake City, Utah

⁴Division of Pediatric Neurosurgery, Department of Neurosurgery, Texas Children's Hospital, Baylor College of Medicine, Houston, Texas

⁵Division of Neurosurgery, Hospital for Sick Children, Toronto, Canada

⁶Department of Pediatrics, University of Washington/Seattle Children's Hospital, Seattle, Washington

⁷Department of Neurosurgery, University of Washington/Seattle Children's Hospital, Seattle, Washington

Abstract

Object—There is little consensus regarding the indications for surgical CSF diversion (either with implanted temporizing devices [reservoir or subgaleal shunt] or shunt alone) in preterm infants with posthemorrhagic hydrocephalus. The authors determined clinical and neuroimaging factors associated with the use of surgical CSF diversion among neonates with intraventricular hemorrhage (IVH), and describe variations in practice patterns across 4 large pediatric centers.

Methods—The use of implanted temporizing devices and conversion to permanent shunts was examined in a consecutive sample of 110 neonates surgically treated for IVH related to

Address correspondence to: Jay Riva-Cambrin, M.D., M.Sc., Department of Neurosurgery, Division of Pediatric Neurosurgery, 100 North Mario Capecchi Drive, Salt Lake City, Utah 84113. Jay.Riva-Cambrin@hsc.utah.edu.

Disclosure

The HCRN is supported by philanthropic funds and the National Institute of Neurological Disorders and Stroke Grant No. 1RC1NS068943-01. Dr. Simon is supported by Award No. K23NS062900 from the National Institute of Neurological Disorders and Stroke, the Child Health Corporation of America via the Pediatric Research in Inpatient Setting Network Executive Council, and Seattle Children's Center for Clinical and Translational Research. None of the sponsors participated in the design and conduct of the study; collection, management, analysis, and interpretation of the data; or preparation, review, or approval of the manuscript. None of the authors have potential financial or personal conflicts of interest to disclose.

Author contributions to the study and manuscript preparation include the following. Conception and design: Riva-Cambrin, Shannon, Wellons. Acquisition of data: Riva-Cambrin, Shannon, White-head, Kulkarni, Wellons. Analysis and interpretation of data: Riva-Cambrin, Holubkov, Drake, Kestle, Wellons. Drafting the article: Riva-Cambrin. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Riva-Cambrin.

prematurity from the 4 clinical centers of the Hydrocephalus Clinical Research Network (HCRN). Clinical, neuroimaging, and so-called processes of care factors were analyzed.

Results—Seventy-three (66%) of the patients underwent temporization procedures, including 50 ventricular reservoir and 23 subgaleal shunt placements. Center ($p < 0.001$), increasing ventricular size ($p = 0.04$), and bradycardia ($p = 0.07$) were associated with the use of an implanted temporizing device, whereas apnea, occipitofrontal circumference (OFC), and fontanel assessments were not. Implanted temporizing devices were converted to permanent shunts in 65 (89%) of the 73 neonates. Only a full fontanel ($p < 0.001$) and increased ventricular size ($p = 0.002$) were associated with conversion of the temporizing devices to permanent shunts, whereas center, OFCs, and clot characteristics were not.

Conclusions—Considerable center variability exists in neurosurgical approaches to temporization of IVH in prematurity within the HCRN; however, variation between centers is not seen with permanent shunting. Increasing ventricular size—rather than classic clinical findings such as increasing OFCs—represents the threshold for either temporization or shunting of CSF.

Keywords

hydrocephalus; preterm infant; temporizing implant; intraventricular hemorrhage; cerebrospinal fluid shunt; Hydrocephalus Clinical Research Network

The intensive care and management of preterm, very low birth weight infants continues to be one of the fastest growing frontiers in medicine. Developed nations face burgeoning incidence rates of premature infants who are surviving from ever earlier gestational stages.^{2,6,8,17} The survivors frequently have multiple complex medical problems such as NEC,³ cognitive disability,^{1,2,16} IVH,¹⁰ and hydrocephalus.^{11,12,15,19}

It has been estimated that 1.5% of all live births in the US are preterm, and that these infants have very low birth weights (62,000 infants/year).⁶ Hintz et al.⁸ demonstrated that approximately 36% of extremely premature (< 25 weeks) infants develop Grade III or IV IVH. In a retrospective, multicenter cohort of preterm infants with IVH within the HCRN, our group has found that 40% of these patients required some treatment for hydrocephalus, of which 78% underwent permanent shunt insertions.¹⁸ Hence, we can expect approximately 9000 new children per year in the US with hydrocephalus from prematurity alone.

The management of hydrocephalus in this population is complex. At the moment, however, there is little evidence to guide this management. The goal of this study was to examine the factors associated with surgical CSF diversion, thereby informing the development of algorithms for the treatment of preterm infants with IVH and hydrocephalus. The primary objective of this study was to determine the clinical and neuroimaging factors associated with 1) the implantation of temporizing devices and 2) the conversion of these temporizing devices to permanent CSF shunts among premature neonates with IVH. The secondary objective was to describe variations in practice patterns across 4 pediatric neurosurgical centers.

Methods

Study Design

This retrospective cohort study included infants treated at HCRN centers between January 1, 2000, and August 31, 2008. Each of the 4 centers consecutively enrolled the last 25–32 children who exclusion criteria. The study was developed and conducted through the HCRN, which, at the time of the study implementation, included 4 clinical centers

representing 2 countries and a data coordinating center. All 5 centers obtained institutional review board approval at their respective locales, all with waiver of consent.

Patient Sample

Enrolled patients included preterm infants born at <37 weeks of gestation, with birth weights of < 1500 g and Grade III or IV IVHs on neuroimaging who underwent implantation of a temporizing device or a permanent CSF shunt for IVH-related hydrocephalus at an HCRN center. Infants meeting these criteria who died within 1 month of birth were excluded.

Treatment Outcomes

Implanted temporizing devices included either ventricular reservoirs¹² or subgaleal shunts.⁷ No external ventricular devices were used as temporizing measures in this study. Conversion to a permanent CSF shunt was our proxy for permanent hydrocephalus and was recorded only for those patients who had previously had an implanted temporizing device placed within 6 months. Endoscopic third ventriculostomy was not used in any patients in this study.

Clinical Characteristics

Clinical factors were evaluated via retrospective chart review. At least 20% of the abstracted chart data were collected in duplicate at each center to confirm and report abstraction accuracy. Gestational age, birth weight, sex, race or ethnicity, apnea and bradycardia episodes, and center of treatment were all recorded. The presence of splayed sutures and a bulging or full fontanel was documented if noted by either neurosurgery or neonatology physicians in the patient's chart. The OFCs and percentiles were recorded at birth, 32 weeks, 41 weeks, and before surgery. Previous NEC, meningitis, and septicemia were recorded if any of these were documented at the HCRN center either prior to the implantation of a temporizing device or prior to 32 weeks of gestation for those who did not undergo such a procedure. The NEC was further categorized as absent, medical NEC (no drain or resection required), or surgical NEC (required drain and/or bowel resection).

Neuroimaging Factors

These factors were abstracted by a pediatric neurosurgeon at each center. There was no set protocol at any center during the time of the study that determined if and when neuroimaging was obtained, other than as deemed clinically necessary. Baseline neuroimaging (CT scanning, MRI, or ultrasound imaging) was defined as the first cranial image available to the HCRN center that identified the Grade III or IV IVH. Clot size was recorded as the maximal length in millimeters of the intraventricular clot in any plane. Clots were described as hyperintense if they were brighter, isointense if equal, and hypointense if they were darker than surrounding white matter on CT theinclusionand or ultrasound imaging. The anatomical location within the ventricle with the maximal clot burden was chosen as the clot location. The FOR was used as a validated quantitative measure of ventricle size.^{9,14} The pattern of ventriculomegaly was defined as either a triventricular pattern (only the lateral and third ventricles are enlarged) or a communicating pattern (lateral, third, and fourth ventricles are all enlarged). No baseline imaging could be found in 9 patients, and in 5 others the IVH had already dissipated; therefore, clot characteristics were missing for these patients.

To select images from comparable time points in treated and untreated patients, the pretemporization procedure or Week 32 imaging was defined as the last cranial imaging study prior to the temporizing device implantation, or the imaging study obtained closest to the infant's 32nd week of gestation for those in whom a temporizing device was not used.

This time point was chosen because 32 weeks was both the mean and the median gestational age at which temporizing devices were inserted in the group that underwent surgery. Pretemporization procedure or Week 32 imaging was missing for 22 patients.

Preshunt conversion or Week 41 imaging was obtained only in those patients who underwent implantation of a temporizing device. It was defined as the last cranial imaging session prior to shunt insertion or the imaging study obtained closest to the infant's 41st week of gestation for those in whom a CSF shunt was not necessary. Again, this time point was chosen because 41 weeks was both the mean and the median gestational age at which implanted temporizing devices were converted to shunts. Preshunt conversion or Week 41 imaging was missing in 7 eligible patients.

Processes of Care Factors

Secondary outcomes examined included whether the infant's first NICU admission was at an HCRN center, and if not, the timing and reason (neurosurgical or other) for the transfer was recorded. Age at admission to the HCRN center's NICU and neurosurgery consultation were also examined. We also collected the total LOS, the number of admissions per patient, and the number and type of cranial imaging studies completed at the tertiary (HCRN-affiliated) center only.

Statistical Analysis

Comparisons among centers for each factor were conducted using chi-square analyses and the Fisher exact test for categorical variables and the Wilcoxon rank-sum test and the Kruskal-Wallis nonparametric test for continuous variables. The associated p values are reported.

For the entire cohort, the association of individual factors with the use of an implanted temporizing device was assessed using chi-square analyses and the Fisher exact test for categorical variables and the Wilcoxon rank-sum test and the Kruskal-Wallis nonparametric test for continuous variables. Similar comparisons were conducted to determine the association with conversion to a permanent CSF shunt.

Stepwise logistic regression was used to construct the multivariate model for factor association with the use of an implanted temporizing device. Tests for colinearity were performed among the significant risk factors identified using the univariate scheme. Only the variables with significance in univariate analyses ($p < 0.05$) were tested in multivariate logistic regression. Regression modeling is not reported for conversion to CSF shunt; the models examined were unstable because the number of infants with an implanted temporizing device who did not undergo CSF shunt placement was very low. All statistical analysis was conducted using SAS version 9.2 software.

Results

Baseline Clinical and Neuroimaging Characteristics

A total of 110 premature infants who met inclusion criteria across 4 HCRN centers were evaluated in this study. Their baseline clinical characteristics are shown in Table 1. As expected, gestational age and birth weight covaried and demonstrated a small yet significant difference between individual centers, with a range of 1.5 weeks in gestational age. No differences were seen among the centers in terms of medical comorbidities. Overall, 16% of these infants had NEC (two-thirds of which was surgery-related), 3% had meningitis, and 18% had septicemia prior to any neurosurgical interventions. No deaths were recorded in this surgical sample.

Baseline neuroimaging data are shown in Table 2. The mean FOR (ventricle size) of 0.59 qualitatively correlates to moderate-to-severe ventriculomegaly.⁹ Two-thirds of patients had a triventricular pattern of ventriculomegaly rather than a communicating pattern. Grade of IVH, clot characteristics, FOR, and the ventriculomegaly pattern differed significantly among HCRN centers.

Factors Associated With Use of an Implanted Temporizing Device

In the cohort, 73 (66%) of 110 patients underwent a temporization procedure, whereas the remaining 37 patients underwent placement of a permanent CSF shunt immediately, at a mean gestational age of 39.5 weeks. Implanted temporizing devices included either ventricular reservoirs (50 [68%] of 73) or subgaleal shunts (23 [32%] of 73). Clinical factors associated with use of a temporizing device procedure included bradycardia episodes ($p = 0.02$), a bulging or full fontanel ($p = 0.03$), splayed cranial sutures ($p = 0.001$), and HCRN center ($p < 0.001$), but not NEC or preoperative OFC (Table 3). Radiological factors associated with use of a temporizing device included pretemporization procedure or Week 32 FOR ($p = 0.003$) and a communicating pattern of ventriculomegaly ($p = 0.02$), but not baseline FOR or the presence of residual intraventricular clot. In the test for collinearity of the significant risk factors identified, the only interaction found was between a bulging or full fontanel and splayed sutures. Of these 2 colinear factors, fontanel was selected as the candidate for multivariate regression modeling, because it is more widely used and thought to be more clinically reliable by the authors. In multivariate analysis, only HCRN center ($p < 0.001$), higher FOR ($p = 0.04$), and bradycardia episodes ($p = 0.07$) remained associated with the use of an implanted temporizing device. This model calibrated significantly (Hosmer-Lemeshow statistic $p = 0.53$) and was very accurate, with a c-statistic of 0.935.

Factors Associated With Conversion of an Implanted Temporizing Device to a Permanent CSF Shunt

A total of 102 (93%) of 110 neonates in this study ultimately underwent CSF shunt placement. Of the 73 children who underwent a temporization procedure, in 65 (89%) the initial treatments were converted to permanent CSF shunts. Clinical and neuroimaging factors univariately associated with conversion to a permanent shunt among those who underwent a temporization procedure included a bulging or full fontanel ($p < 0.001$) and higher preshunt conversion or Week 41 FOR ($p = 0.002$) (Table 4). Splayed sutures, OFC percentile change, the OFC prior to either surgery decision point, and HCRN center were not.

Processes of Care Among Centers

Only a minority of the cohort (10%, range 0%–20%) was first admitted to an HCRN center NICU, demonstrating the tertiary referral nature of our member centers for this condition (Table 5). More than three-quarters (78%) of transfers were for neurosurgical issues, and transfers only rarely (9%) occurred within these neonates' 1st week of birth. Patient transfer rates within 7 days of birth did not significantly differ among centers. There were differences, however, in center-specific mean ages at neurosurgical consultation, ranging from 31 to 62 days of age ($p = 0.009$).

Many differences in processes of care for these patients were identified among centers. The mean number of admissions to the HCRN center per patient in the first 3 months of life varied significantly ($p = 0.02$), from 1.3 to 1.7 (Fig. 1 left). The median total LOS at the HCRN center per patient varied significantly ($p < 0.001$), from 15 to 84 days (Fig. 1 right). While in the HCRN center's NICU, patients underwent an average of 9 (range 0–28) cranial neuroimaging studies, including ultrasonography (mean 6.2/patient) and CT (mean 2.4/patient); however, the total number of cranial images per patient varied significantly among

centers ($p < 0.001$) (Fig. 2). This variation in imaging among centers was seen for ultrasound ($p < 0.001$) and CT only ($p < 0.001$); the rarer use of MRI was consistent among centers (mean 0.3/patient, not statistically significant).

Discussion

In this large multicenter cohort of 110 premature infants with Grade III or IV IVH who were surgically treated for hydrocephalus, we found that 73 patients (66%) were treated with temporization procedures at a mean age of 32 weeks, and in 37 (34%) CSF shunt placement was performed immediately. Factors independently associated with temporization procedures included center, larger ventricular size, and episodic bradycardia. In 89% of the infants, the temporizing device was converted to a permanent CSF shunt. A full or bulging fontanel and larger ventricular size were associated with this conversion. Significant variation in neurosurgical management for these neonates existed among HCRN centers.

Among the centers involved in this study, significant variation was seen between the treated populations, especially in terms of neuroimaging findings (Table 2). We believe that the differences in clot size, density, location, and triventricular ventriculomegaly were, in part, related to interpretation issues, given that a separate pediatric neurosurgeon at each site abstracted these data points. Strict criteria were given a priori, but ultrasound imaging (which was used most) can vary significantly in quality and can be difficult to abstract. Future studies will require a centralized reading for exactly these issues. The FOR, as a measure of ventricular size, is very reliable between observers.⁹ The FOR did differ significantly both at baseline and prior to temporization; however, prior to temporization, the FORs ranged only from 0.62 to 0.68, which is of minimal clinical significance. The age at admission to an HCRN center NICU did not account for the baseline difference in FOR. We suspect that the slightly more extreme prematurity at centers C and D contributed.

In addition to larger preoperative ventricular size and the presence of bradycardia episodes, the center where a neonate is treated is the strongest predictor of the decision to use a temporizing device. This “center effect” is probably due to a compilation of several highly variable factors within each center and provides a clinical confirmation of a recent finding from a questionnaire study among neonatologists.⁵ The most probable factor accounting for center variation is neurosurgeon treatment thresholds, because no documented treatment algorithms or strategies for temporization existed during the years of this study at any of the centers. However, other hospital-specific factors such as admission patterns (that is, a single long-term tertiary NICU admission under the auspices of neurosurgery vs multiple short-term tertiary NICU admissions with transfers from the community hospital) in combination with varying neonatology philosophies of care may be contributing in a small way.

Degree of ventriculomegaly is more strongly associated with the use of a temporizing device than clinical signs such as apnea, split cranial suture, bulging fontanel, and OFC measurements (with the exception of bradycardia). This intriguing observation is consistent with previously published studies,^{4,13} which have suggested that the premature infant’s brain is highly compliant to increasing intraventricular size, and it is not until later in the hydrocephalus process that the pressure begins to expand the cranial vault size, thereby increasing OFCs, splitting the sutures, and bulging the fontanel.

Whereas implantation of temporizing devices in this population is highly variable between centers, the conversion of these devices to permanent CSF shunts is not. Factors associated with permanent CSF shunt placement are bulging or full fontanel and larger ventricular size, which occurred despite temporization or during a trial of weaning of taps in the group with reservoirs. No specific tapping protocol was followed at any of the centers that used

ventricular reservoirs during the timeline of the study. These risk factors are more consistent with traditionally held views within neurosurgical practice.⁵ Thus, perhaps more consistency across centers is not unexpected. Again, it is interesting to note that apneas, bradycardias, splayed sutures, and OFCs were not predictive of the need for conversion to permanent CSF shunting.

An issue of concern at all centers is that these infants were referred to either a neurosurgery-associated NICU or the neurosurgery service in a delayed manner, with a mean of 44 days, especially considering that hemorrhages usually occur within the 1st week of birth. However, the degree of delay for neurosurgery consultation varied significantly ($p = 0.009$) between centers (range 31–62 days). Half of centers tend to admit the neonate and perform all treatment at that tertiary NICU, thereby having fewer admissions per patient and a longer LOS. The other centers focus the care at the referring NICU and transfer the infant more frequently but for short durations to the tertiary center for specific treatments only. Decentralized care poses logistical challenges both for standardizing treatment decisions and for prospective data collection when studying the care of these infants.

The clinical centers of the HCRN also differed significantly in the type of temporizing devices used (subcutaneous reservoir vs subgaleal shunt), patient chronological age at neurosurgical consult, and the frequency and modalities of neuroimaging used. We believe that these findings are representative of most tertiary care pediatric neurosurgery centers across North America. For any meaningful future study examining this population, these factors must be standardized for the results to maintain internal validity.

Limitations of the Study

The scope of this project was limited to the group of preterm infants with IVH who underwent neurosurgical intervention. The study was retrospective, and data collection was limited to what was recorded in the chart. Given the number of factors examined in analyses for the primary objective, our study had limited statistical power to demonstrate significance. This work was designed as a pilot in preparation for creating consensus surgical treatment algorithms for an upcoming prospective study. Therefore, we must temper our results and conclusions until they can be validated in the prospective study.

Conclusions

In this large multicenter cohort of 110 preterm infants with IVH who were surgically treated for hydrocephalus, 73 (66%) underwent temporization procedures. Aside from larger ventricular size and the presence of bradycardia, there was a significant “center effect” in determining whether patients underwent a temporization procedure. We believe, therefore, that standardized algorithms for this surgical decision point are necessary not only for future study but also for optimal patient care. Algorithms dictating this decision should weigh episodic bradycardia and ventricle size preferentially to other clinical findings of OFC increases or apnea episodes. They will need to standardize the timing of neurosurgical consultation and the frequency and modality of neuroimaging. Finally, attempts to standardize care will need to apply to care fragmented between referring and tertiary NICUs.

In 89% of the infants who underwent temporization procedures, the temporizing device was converted to a permanent CSF shunt. The decision to convert these temporizing devices into permanent CSF shunts was uniform across centers and was dominated by larger ventricle size and a bulging or full fontanel.

Acknowledgments

The HCRN is a collaboration of 5 clinical pediatric neurosurgical centers and a Data Coordinating Center dedicated to conducting meaningful clinical investigations in pediatric hydrocephalus. The HCRN consists of the following institutions: Primary Children's Medical Center/University of Utah, Salt Lake City, Utah (John Kestle, Jay Riva-Cambrin, Marion Walker, Tracey Bach, Marcie Langley, Jeff Yearley, Richard Holubkov, and Michelle Miskin); Hospital for Sick Children/University of Toronto, Canada (Abhaya Kulkarni, James M. Drake, and Lindsay O'Donnell); Children's Hospital of Alabama/University of Alabama at Birmingham, Alabama (Jerry Oakes, John Wellons, and Chevis Shannon); Texas Children's Hospital/Baylor College of Medicine, Houston, Texas (William Whitehead, Thomas Luerksen, and Sheila Nguyen Ryan); and Seattle Children's Hospital/University of Washington, Seattle, Washington (Sam Browd, Tamara Simon, and Amy Anderson).

The authors thank Kristin Kraus for editorial assistance with this paper.

Abbreviations used in this paper

FOR	frontal and occipital horn ratio
HCRN	Hydrocephalus Clinical Research Network
IVH	intraventricular hemorrhage
LOS	length of stay
NEC	necrotizing enterocolitis
NICU	neonatal ICU
OFC	occipito-frontal circumference

References

- Adams-Chapman I, Hansen NI, Stoll BJ, Higgins R. Neurodevelopmental outcome of extremely low birth weight infants with posthemorrhagic hydrocephalus requiring shunt insertion. *Pediatrics*. 2008; 121:e1167–e1177. [PubMed: 18390958]
- Allen MC. Neurodevelopmental outcomes of preterm infants. *Curr Opin Neurol*. 2008; 21:123–128. [PubMed: 18317268]
- Carter BM. Treatment outcomes of necrotizing enterocolitis for preterm infants. *J Obstet Gynecol Neonatal Nurs*. 2007; 36:377–385.
- de Vries LS, Liem KD, van Dijk K, Smit BJ, Sie L, Rademaker KJ, et al. Early versus late treatment of posthaemorrhagic ventricular dilatation: results of a retrospective study from five neonatal intensive care units in The Netherlands. *Acta Paediatr*. 2002; 91:212–217. [PubMed: 11952011]
- Dykes FD, Dunbar B, Lazarra A, Ahmann PA. Posthemorrhagic hydrocephalus in high-risk preterm infants: natural history, management, and long-term outcome. *J Pediatr*. 1989; 114:611–618. [PubMed: 2926574]
- Eichenwald EC, Stark AR. Management and outcomes of very low birth weight. *N Engl J Med*. 2008; 358:1700–1711. [PubMed: 18420502]
- Fulmer BB, Grabb PA, Oakes WJ, Mapstone TB. Neonatal ventriculosubgaleal shunts. *Neurosurgery*. 2000; 47:80–84. [PubMed: 10917350]
- Hintz SR, Poole WK, Wright LL, Fanaroff AA, Kendrick DE, Laptook AR, et al. Changes in mortality and morbidities among infants born at less than 25 weeks during the post-surfactant era. *Arch Dis Child Fetal Neonatal Ed*. 2005; 90:F128–F133. [PubMed: 15724036]
- Kulkarni AV, Drake JM, Armstrong DC, Dirks PB. Measurement of ventricular size: reliability of the frontal and occipital horn ratio compared to subjective assessment. *Pediatr Neurosurg*. 1999; 31:65–70. [PubMed: 10592474]
- Levy ML, Masri LS, McComb JG. Outcome for preterm infants with germinal matrix hemorrhage and progressive hydrocephalus. *Neurosurgery*. 1997; 41:1111–1118. [PubMed: 9361065]
- McCallum JE, Turbeville D. Cost and outcome in a series of shunted premature infants with intraventricular hemorrhage. *Pediatr Neurosurg*. 1994; 20:63–67. [PubMed: 8142284]

12. McComb JG, Ramos AD, Platzker AC, Henderson DJ, Segall HD. Management of hydrocephalus secondary to intraventricular hemorrhage in the preterm infant with a subcutaneous ventricular catheter reservoir. *Neurosurgery*. 1983; 13:295–300. [PubMed: 6621842]
13. Müller WD, Urlesberger B. Correlation of ventricular size and head circumference after severe intra-periventricular haemorrhage in preterm infants. *Childs Nerv Syst*. 1992; 8:33–35. [PubMed: 1576604]
14. O'Hayon BB, Drake JM, Ossip MG, Tuli S, Clarke M. Frontal and occipital horn ratio: A linear estimate of ventricular size for multiple imaging modalities in pediatric hydrocephalus. *Pediatr Neurosurg*. 1998; 29:245–249. [PubMed: 9917541]
15. 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*. 1997; 40:983–989. [PubMed: 9149257]
16. Resch B, Gedermann A, Maurer U, Ritschl E, Müller W. Neurodevelopmental outcome of hydrocephalus following intra-/periventricular hemorrhage in preterm infants: short- and long-term results. *Childs Nerv Syst*. 1996; 12:27–33. [PubMed: 8869171]
17. Tyson JE, Parikh NA, Langer J, Green C, Higgins RD. Intensive care for extreme prematurity—moving beyond gestational age. *N Engl J Med*. 2008; 358:1672–1681. [PubMed: 18420500]
18. Wellons JC III, Shannon CN, Kulkarni AV, Simon TD, Riva-Cambrin J, Whitehead WE, et al. A multicenter retrospective comparison of conversion from temporary to permanent cerebrospinal fluid diversion in very low birth weight infants with posthemorrhagic hydrocephalus. *Clinical article. J Neurosurg Pediatr*. 2009; 4:50–55. [PubMed: 19569911]
19. Willis BK, Kumar CR, Wylen EL, Nanda A. Ventriculosubgaleal shunts for posthemorrhagic hydrocephalus in premature infants. *Pediatr Neurosurg*. 2005; 41:178–185. [PubMed: 16088252]

Fig. 1. Histograms demonstrating the variability between centers of the HCRN in the number of admissions per patient in the first 3 months of life (**left**) and the median total days in the hospital per patient over the same time period (**right**).

Fig. 2. Box plots demonstrating center variability in the total number of cranial neuroimages per patient.

TABLE 1

Baseline clinical characteristics of the multicenter cohort*

Characteristic	HCRN	Center A	Center B	Center C	Center D	p Value
no. of patients	110	25	32	28	25	
mean gestational age at birth in wks	26.6 ± 2.0	27.2 ± 1.8	27.1 ± 2.4	25.7 ± 1.8	26.2 ± 1.7	0.02
mean birth weight in g	940 ± 244	1063 ± 234	1009 ± 243	861 ± 239	822 ± 175	<0.001
no. of males (%)	62 (56)	16 (64)	15 (47)	15 (54)	16 (64)	NS
no. w/NEC (%)						
no	92 (84)	24 (96)	25 (78)	24 (86)	19 (76)	NS
yes, medical	6 (5)	0 (0)	4 (13)	0 (0)	2 (8)	
yes, surgical	12 (11)	1 (4)	3 (9)	4 (14)	4 (16)	
no. w/previous meningitis (%)	3 (3)	1 (4)	1 (3)	1 (4)	0 (0)	NS
no. w/previous septicemia (%)	20 (18)	1 (4)	5 (16)	6 (21)	8 (32)	NS

* The means are expressed ± SD throughout.

Abbreviation: NS = not significant.

TABLE 2

Baseline versus pretemporization procedure or Week 32 neuroimaging characteristics

Factor	HCRN	Center A	Center B	Center C	Center D	p Value
baseline neuroimaging	96*	25	32	28	25	
no. w/Grade IV IVH (%)	50 (52)	14 (56)	9 (28)	9 (32)	18 (72)	0.008
mean clot size in mm	22 ± 13	29 ± 13	19 ± 8	27 ± 16	13 ± 7	<0.001
no. w/clot density (%)	96	23	26	22	25	
hyperintense	69 (72)	17 (74)	24 (92)	9 (41)	19 (76)	0.002
isotense	12 (13)	3 (13)	2 (8)	6 (27)	1 (4)	
hypointense	15 (16)	3 (13)	0 (0)	7 (32)	5 (20)	
no. w/ventricular clot location (%)	96	25	32	28	25	
frontal	13 (14)	0 (0)	8 (31)	0 (0)	5 (20)	<0.001
body	52 (54)	12 (52)	10 (38)	19 (86)	11 (44)	
atrium	21 (22)	8 (35)	8 (31)	1 (5)	4 (16)	
temporal horn	1 (1)	0 (0)	0 (0)	0 (0)	1 (4)	
occipital horn	9 (9)	3 (13)	0 (0)	2 (9)	4 (16)	
mean FOR [‡]	0.59 ± 0.11	0.54 ± 0.10	0.56 ± 0.15	0.62 ± 0.06	0.64 ± 0.11	0.003
no. w/triventricular ventriculomegaly (%)	66 (65) [‡]	21/24 (88)	26/28 (93)	12/26 (46)	7/24 (29)	<0.001
pretemporization procedure or Wk 32 imaging	88 [‡]	24	22	21	21	
no. w/clot present (%)	79 (90)	21 (88)	21 (95)	16 (76)	21 (100)	NS
mean clot size in mm	23 ± 16	34 ± 20	16 ± 7	26 ± 19	16 ± 6	<0.001
no. w/clot density (%)	80	21	19	17	22	
hyperintense	41 (51)	8 (38)	16 (84)	4 (24)	12 (55)	<0.001
isointense	21 (26)	9 (43)	3 (16)	7 (41)	2 (9)	
hypointense	18 (23)	4 (19)	0 (0)	6 (35)	8 (36)	
mean FOR	0.66 ± 0.07	0.68 ± 0.05	0.63 ± 0.07	0.62 ± 0.05	0.68 ± 0.07	0.002
no. w/triventricular ventriculomegaly (%)	52/88 (59)	14/24 (58)	19/21 (90)	11/22 (50)	8/22 (36)	0.003

* Baseline neuroimaging could not be obtained for 9 patients, and in 5 others the clot had already dissipated (therefore denominator was 96 for all 4 HCRN centers, and as given for the individual institutions).

[†] Baseline neuroimaging could not be obtained for 9 patients (therefore denominator was 101).

[‡] Preoperative or 32-week imaging studies were missing in 22 patients (denominator was 88). Where more clarification was needed, the numerator and denominator are both given.

TABLE 3

Factors associated with the use of an implanted temporizing device

Factor	Patients w/Temporizing Devices	Patients w/o Temporizing Devices	p Value	
			Univariate	Multivariate
no. of patients (%)	73 (66)	37 (34)		
clinical				
mean gestational age at birth (wks)	26.6	26.4	NS	
mean birth weight (g)	943.4	934.5	NS	
male sex (%)	54.8	59.5	NS	
race or ethnicity, categorical *	—	—	NS	
NEC (%)	15.1	18.9	NS	
apnea episodes (%)	60.3	47.1	NS	
bradycardia episodes (%)	53.4	29.4	0.02	0.07
bulging or full fontanel (%) †	83.3	62.5	0.03	NS
splayed sutures (%) ‡	74	41.2	0.001	‡
mean OFC percentile ‡	66.5	61.9	NS	
no. at HCRN center (%)			<0.001	<0.001
A	24 (32.9)	1 (2.7)		
B	8 (11.0)	24 (64.9)		
C	19 (26.0)	9 (24.3)		
D	22 (30.1)	3 (8.1)		
neuroimaging §				
intraventricular clot present (%) †	88.9	92	NS	
clot location, categorical †¶	—	—	NS	
clot density, categorical †¶	—	—	NS	
mean clot size at baseline (mm)	22.7	19.4	NS	
mean FOR at baseline	0.59	0.59	NS	
mean FOR preop or at 32 wks †	0.67	0.62	0.003	0.04
triventricular ventriculomegaly (%) †	50.8	79.2	0.02	NS

* These categorical data (number [%] of each subgroup) are not reported because the data would unmask the centers, and this variable was not significant.

† Measured at the time just prior to the implantation of the temporizing device or at 32 weeks' gestation for those without devices.

‡ Collinearity with fontanel; therefore removed from model.

§ Twenty-two patients had missing preoperative or 32-week imaging studies (denominator is 88).

¶ These categorical data (number [%] of each subgroup) are not reported for purposes of table clarity and brevity.

TABLE 4

Factors associated with the conversion of an implanted temporizing device to a permanent shunt

Factor	Patients w/Temporizing Devices		Univariate p Values
	Converted to Shunt	Not Converted to Shunt	
no. of patients (%)	65 of 73 (89)	8 of 73 (11)	
clinical characteristics			
mean gestational age at birth (wks)	26.6	26.8	NS
mean birth weight (g)	938.1	986.9	NS
male sex (%)	58.5	25	NS
race or ethnicity, categorical *	—	—	NS
NEC (%)	15.4	12.5	NS
apnea episodes (%)	48.4	37.5	NS
bradycardia episodes (%)	46.9	37.5	NS
bulging/full fontanel (%) †	71	0	<0.001
splayed sutures (%) †	64.6	37.5	NS
% mean OFC at temporization or 32 wks	67.6	58.3	NS
% mean OFC at shunt or 41 wks	68.7	60.3	NS
% OFC crossing >30 percentiles	34.4	28.6	NS
no. at HCRN center (%)			NS
A	21 (32.3)	3 (37.5)	
B	7 (10.8)	1 (12.5)	
C	18 (27.7)	1 (12.5)	
D	19 (29.2)	3 (37.5)	
neuroimaging characteristics ‡			
intraventricular clot present (%) †	43.1	83.3	NS
clot location, categorical †§	—	—	NS
clot density, categorical †§	—	—	NS
mean clot size at baseline (mm)	22.3	26.2	NS
mean clot size preshunt or at 41 wks (mm) †	8.2	11.8	NS
mean FOR at baseline	0.58	0.63	NS
mean FOR at preshunt or at 41 wks †	0.66	0.55	0.002
triventricular ventriculomegaly (%) †	47.5	83.3	NS

* These categorical data (number [%] of each subgroup) are not reported because the data would unmask the centers, and this variable was not significant.

† Measured at the time just prior to the implantation of the permanent shunt or at 41 weeks' gestation for those without shunts.

‡ Six had missing preshunt or 41-week imaging studies (denominator is 67).

§ These categorical data (number [%] of each subgroup) are not reported for purposes of table clarity and brevity.

TABLE 5

Processes of care between centers

Process of Care	HCRN	Center A	Center B	Center C	Center D	p Value
no. of patients	110	25	32	28	25	
no. w/1st NICU admission at HCRN center NICU (%)	11 (10)	1 (4)	0 (0)	5 (18)	5 (20)	0.01
no. w/transfer to HCRN center NICU w/in 7 days of birth (%)	9 (9)*	2 (8)	2 (6)	1 (4)	4 (20)	NS
no. in whom a neurosurgical issue was reason for transfer (%)	77 (78)*	22 (92)	22 (69)	18 (78)	15 (75)	NS
mean age at admission to HCRN center NICU in days	43 ± 59	30 ± 17	51 ± 36	56 ± 106	33 ± 31	NS
mean age at neurosurgery consultation in days	44 ± 32	31 ± 15	62 ± 41	41 ± 22	37 ± 29	0.009

* Eleven patients had missing data (denominator of 99).