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Original Articles

Cerebellar Injury in Term Infants: Clinical Characteristics, Magnetic Resonance Imaging Findings, and Outcome

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Although cerebellar injury in the premature infant is an increasingly recognized form of neonatal brain injury, its structural and functional outcomes remain poorly defined in the term infant. The objective of this cross-sectional study was to characterize the clinical and magnetic resonance imaging features and neurodevelopmental outcome in children, born at term, with cerebellar injury. Over a 5-year period, 20 infants were identified with ischemic (n = 3) or hemorrhagic (n = 17) cerebellar injury. Lesions were small (<1 cm) in 12 cases, and large in 8 cases. Prenatal and intrapartum factors frequently documented in term infants with cerebellar injury included primiparity (55%), advanced maternal age (30%), group B streptococcus-positive mothers (35%), abnormal fetal heart rate (35%), instrumented delivery (30%), and cesarean section (25%). At follow-up of 18 cases (median age, 32 months), 39% had neurologic abnormalities. Gross motor delays, expressive language deficits, and externalizing behavioral problems were the most common (44%). Cognitive deficits were present in one third of cases. Larger cerebellar lesions were associated with significantly lower cognitive, gross motor, expressive language, and social-behavioral scores. Cerebellar injury in the term infant is associated with a broad spectrum of neurodevelopmental disabilities, particularly in infants with large cerebellar lesions.

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Introduction

Until recently, cerebellar injury had been considered a rare condition in the neonatal period diagnosed primarily at autopsy [1,2]. Increasingly, however, cerebellar injury is recognized in the high-risk newborn requiring intensive care, as a result of more widespread availability of advanced neuroimaging techniques [3,4]. Earlier studies reported severe forms of cerebellar hemorrhagic injury in term infants presenting with features of brainstem compression [3,5,6]. In the term infant, cerebellar hemorrhagic injury is frequently associated with traumatic delivery, such as breech presentation, instrumentation-assisted delivery, and prolonged labor with excessive cranial molding [3,4,6]. Cerebellar hemorrhagic injury associated with traumatic delivery is believed to result from severe distortion and disruption of the venous structures within the compliant neonatal skull, leading to laceration of the tentorium or falx, or due to direct traumatic cerebellar laceration along the vermis [3,4,7]. Increases in cerebral venous pressure have also been implicated, as seen in infants on extracorporeal membrane oxygenation or earlier techniques of bag-mask ventilation [8].

The outcome of term infants with cerebellar injury has previously been considered primarily in terms of survival [1,3,4]. Improved medical and surgical management of cerebellar injury has resulted in a significant decrease in mortality. However, the functional outcome of cerebellar injury in the surviving term infant remains poorly defined. The objective of this study was to characterize, by performing follow-up magnetic resonance imaging (MRI) studies and standardized neurodevelopmental outcome testing, the structural and functional outcome in children who had

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been born at term and who had a diagnosis of ischemic or hemorrhagic (either or both) cerebellar injury in the neonatal period.

Subjects, Materials, and Methods

Subjects

For this cross-sectional study, the recruitment pool was all term infants (≥36 weeks gestational age) with a diagnosis of cerebellar injury (ischemic, hemorrhagic, or both), identified through a systematic electronic database search of all computed tomography and MRI studies performed at Children's Hospital Boston from January 2002 through January 2007. All lesions that were identified initially by computed tomography had follow-up MRI studies that confirmed the diagnosis. Excluded were infants with known or suspected brain malformations, major dysmorphic features suggestive of a genetic syndrome, metabolic disorders, or central nervous system infections, as well as infants with extra-axial hemorrhage only (i.e., no cerebellar parenchymal injury).

Once infants met the established inclusion criteria, informed written consent was obtained for enrollment and follow-up cranial MRI studies and standardized neurodevelopmental outcome evaluations were performed. Medical records were reviewed for all infants for pertinent demographic, maternal, and neonatal data. The study was approved by Children's Hospital Boston Committee for Clinical Investigation.

MRI Procedures

All children enrolled in our follow-up study were scanned in a 1.5-T magnetic resonance scanner (Signa System; General Electric, Milwaukee, WI) using a quadrature or 8-channel phased array head coil at Children's Hospital Boston. The MRI approaches included conventional, spin echo T_1-weighted, volumetric spoiled gradient recalled echo T_1-weighted, fast spin echo T_2-weighted, fast spin echo inversion recovery (FSEIR) T_2-weighted, and multiplanar gradient recalled echo susceptibility sensitive sequences. The MRI findings were reviewed by an experienced pediatric neuroradiologist. All MRI studies were reviewed blindly to confirm the diagnosis of ischemic or hemorrhagic cerebellar injury (or both), and to distinguish between parenchymal and extra-axial hemorrhage.

Clinical Data Collection

Medical records were reviewed and demographic, prenatal, intrapartum, and acute postnatal data were collected for all identified infants. Demographic data included gestational age at birth, birth weight, and sex. Maternal data included age, parity, method of conception, single vs multiple gestation, pregnancy-induced hypertension, pre-eclampsia, group B streptococcus status, and any chronic maternal conditions or hematologic abnormalities. Intrapartum factors included significant fetal heart rate abnormalities (i.e., sustained fetal bradycardia with <100 beats/minute, decreased variability, and late decelerations), vaginal vs cesarean birth, use of instrumentation (i.e., forceps or vacuum extraction), Apgar score at 5 minutes, and need for resuscitation (defined as assisted bag-mask ventilation or endotracheal intubation).

Early postnatal data included sex, gestational age, birth weight, apneic episode within 36 hours of birth, need for mechanical ventilation, neonatal seizures, neurosurgical intervention (i.e., craniotomy, cerebrospinal fluid shunt), use of extracorporeal membrane oxygenation, length of neonatal intensive care unit stay, and results of hematology testing.

Neurodevelopmental Outcome Measures

A formal neurologic examination, performed by one of two pediatric neurologists, included assessment of cranial size, cranial nerves, special senses, and motor function (i.e., deep tendon reflexes, muscle tone, muscle strength, coordination, and gait).

For developmental testing, four instruments were used. A licensed pediatric psychologist administered the Mullen Scales of Early Learning [9].The Mullen Scales of Early Learning is a standardized assessment of gross and fine motor, expressive and receptive language, and visual reception skills. Infants scoring below 35 (i.e., 1.5 standard deviations [S.D.] below the mean of 50) were considered delayed in that subdomain. A summary measure of general cognitive function underlying all cognitive performances (early learning composite) was also derived, and a score <78 (i.e., 1.5 S.D. below the normative mean of 100) was defined as abnormal.

The Vineland Adaptive Behavior Scale [10] was also completed by a pediatric licensed psychologist. The Vineland Adaptive Behavior Scale is a discriminative norm-referenced measure of functional status in communication, daily living, socialization, and motor skills in children. Standard scores were generated using a mean of 100, with 1 S.D. = 15. A score of <1.5 S.D. of the normative mean was defined as abnormal.

The Child Behavior Checklist 1.5-5, a preschool measure of child behavioral and emotional problems, was completed by the parents [11]. Externalizing and internalizing problem behavior scores are derived. Internalizing behavior consists of the withdrawn, somatic complaints, and anxious and depressed syndromes scales; externalizing behavior consists of the delinquent and aggressive behavior syndrome scales. Scores were summed to yield a total problem score, as well as externalizing and internalizing behavior problem scores, with higher scores reflecting more behavioral symptoms. Scores were dichotomized to normal vs borderline or clinical range.

The Modified Checklist for Autism in Toddlers was used to screen all children's behaviors for early signs of autism [12]. The Modified Checklist for Autism in Toddlers is a 23-item, yes/no parent-report screening instrument for autistic spectrum disorders. Critical items concern joint attention, interest in other children, response to name, and imitation. Cutoff scores were at least two critical items or three total items on the checklist.

All examiners were blinded to past medical history, the infants' MRI findings, and to each other's clinical findings.

Statistical Analysis

Continuous perinatal data were summarized by using the mean and standard deviation, ordinal characteristics by using the median and range, and categorical factors with percentages. Performance on developmental outcome measures was also described with means and standard deviations for continuous data and proportions for categorical data. Group differences on clinical, MRI, and developmental outcome measures were compared using the *t*-test or Wilcoxon rank sum test for continuous variables.

Results

Characteristics of the Cohort

Initially, 23 term infants were identified, with a diagnosis of neonatal cerebellar parenchymal injury born over a 5-year period (January 2002 through January 2007). All studies were then reviewed by the pediatric neuroradiologist. Three infants initially identified in the search as with cerebellar parenchymal injury were excluded when image review confirmed only extra-axial posterior fossa hemorrhage. Of the remaining 20 infants who met our inclusion criteria, 2 died in the early postnatal period. The remaining 18 infants comprised the final study cohort and were successfully recruited (100% enrollment rate) for follow-up MRI and standardized neurodevelopmental testing.

Pregnancy, labor, and delivery characteristics for the cohort are presented in Table 1. The median gestational age was 39 weeks (range, 36.1-42.0 weeks) and the median birth weight was 3550 g (range, 2010-4175 g). More than half of the mothers were primiparous (55%), more than one third were group B streptococcus positive (35%), and 30% had chronic medical conditions, including multiple sclerosis (n = 1), diabetes mellitus type 1 (n = 1), Crohn's disease (n = 1), rheumatoid arthritis (n = 1), and Factor V Leiden (n = 2). During labor and delivery, more than one third of the original 20 infants had a significantly abnormal fetal heart rate (35%), and 30% required an instrument-assisted vaginal delivery (forceps or vacuum extraction). Five of the 20 infants (25%) were born by emergency cesarean section and required resuscitation (3 bag-mask ventilation; 2 endotracheal intubation) in the delivery room. An additional 5 infants were intubated and ventilated in the neonatal intensive care unit because of apnea.

Postnatally, apneic episodes developed in 14 of the 20 infants (all within 12 hours of birth), and 6 infants developed seizures (all within 36 hours of birth). Neurosurgical intervention was required in 5/20 infants (25%); specifically, 3 required hematoma evacuation and 2 others required ventricular peritoneal shunts. Of note, those infants who developed apnea, seizures, or required neurosurgical intervention all had cerebellar lesions >1 cm in size. Two of the three infants with coagulopathy also had large lesions (see next section). One infant had a diagnosis of cerebellar parenchymal injury identified prior to placement on extracorporeal membrane oxygenation. Factor V Leiden was present in 3 of the 20 infants. Although 35% of mothers had a history of group B streptococcus positivity during pregnancy, there was no case of culture-positive group B streptococcus in the neonatal period. The median length of hospitalization was 6 days (range, 4-32 days), and death resulted in 2 infants (10%).

Acute Neuroimaging Findings

The findings on initial MRI studies of the 20 newborns with cerebellar parenchymal injury are given in Table 2. Mean postnatal age at MRI was 10.4 days $\pm$ 10.2 (S.D.) (range, 3-49 days). Cerebellar hemorrhagic injury was documented in 17 infants (85%) and nonhemorrhagic cerebellar infarction in 3 infants (15%). Bilateral cerebellar hemorrhage occurred most frequently (7/17, or 41%); in three additional cases (3/17, or 18%), bilateral cerebellar hemorrhage also involved the vermis.

Cerebellar lesions were classified as small (<1 cm), located primarily deep within the white matter of the cerebellum (n = 12) (Fig 1A) vs large ($\geq$1 cm); large lesions frequently involved the vermis, the cerebellum, or both (n = 8) (Figs 2A and 3). Of the 12 infants with small lesions, 6 had punctate lesions less than 5 mm in diameter (Fig 4). Combined cerebellar injury and supratentorial (extraparenchymal or parenchymal injury) occurred in 12/20 infants (60%). Specifically, cerebellar injury was associated with choroid plexus-germinal matrix hemorrhage with intraventricular hemorrhage in 6/20 infants (40%). More extensive concomitant supratentorial parenchymal injury was present in 3/20 infants (15%) and included bilateral periatrial white matter hemorrhage, unilateral left temporal hemorrhage, and unilateral right posterior corpus callosum hemorrhage. Of the three infants with supratentorial parenchymal injury, two had large cerebellar lesions. One fifth of the infants (4/20, or 20%) had supratentorial subdural hemorrhage. In no case were significant generalized bleeding problems experienced.

Follow-Up MRI Studies

Eighteen children had follow-up MRI studies between 12 and 56 months (median age, 30 months). The MRI findings included isolated small unilateral or bilateral blood products in the cerebellum (n = 11) (Fig 1B), or large lesions resulting in superior vermis atrophy (n = 5) (Fig 2B) and bilateral atrophy of the medial cerebellum (n = 2). Concomitant supratentorial parenchymal injury was evident at follow-up MRI in 4/18 children (22%), as postoperative changes in left temporal lobe (n = 1), periventricular leukomalacia (n = 1), mild thinning of the corpus callosum (n = 1), and signal abnormality within the periatrial white matter (n = 1).

Neurodevelopmental Outcomes

All 18 children had follow-up neurodevelopmental evaluations by a pediatric neurologist and a psychologist at a median age of 32 months (range, 18-58 months).

Of the 18 children, 7 (39%) had neurologic abnormalities, which included hypotonia (6/7), impaired gait (5/7), abnormal eye alignment (5/7), abnormal deep tendon reflexes (4/7), extraocular abnormalities (4/7), truncal ataxia (4/7), facial weakness (3/7), hypertonia (2/7), visual field defects (2/7), and motor asymmetries (1/7). On MRI, 6 of the 7 children with neurologic abnormalities had large lesions. Of the 11 children with normal neurologic examinations, 10 also had normal developmental testing.

Performance on the Mullen Scales of Early Learning, Vineland Adaptive Behavior Scale, Child Behavior Checklist and Modified Checklist for Autism in Toddlers is summarized in Table 3. Overall mean performance on developmental (Mullen Scales of Early Learning) and functional (Vineland Adaptive Behavior Scale) outcome measures were <1 S.D. below the normative mean of 100. Developmental evaluations revealed that delays (<1.5 S.D. below the mean) in gross motor function and expressive language abilities were most common, occurring in 8 of the 18 survivors (44%). Cognitive deficits were present in one third of the cohort. Functional skills most commonly involved were those in communication and socialization (28% for each).

Behavioral problems were frequently reported by parents on the Child Behavior Checklist, with externalizing behavioral problems twice as common (8/18, or 44%) as internalizing behavioral problems (4/18, or 22%).

Table 1. Clinical characteristics of pregnancy, labor, and delivery of the cohort (n = 20)

Clinical Characteristics	
Pregnancy	
Maternal age > 35 years, no. (%)	6 (30)
Primipara, no. (%)	11 (55)
Group B streptococcus positive, no. (%)	7 (35)
In vitro fertilization, no. (%)	5 (25)
Pregnancy-induced hypertension, no. (%)	4 (20)
Pre-eclampsia, no. (%)	4 (20)
Maternal chronic conditions, no. (%)	6 (30)
Factor V Leiden, no. (%)	2 (10)
Intrauterine growth restriction, no. (%)	2 (10)
Labor and delivery	
Male sex, no. (%)	12 (63)
Singleton, no. (%)	19 (95)
Abnormal fetal heart rate, no. (%)	7 (35)
Vaginal assisted delivery, forceps or vacuum, no. (%)	6 (30)
Cesarean delivery, no. (%)	5 (25)
Resuscitation in delivery room, no. (%)	5 (25)
Apgar score at 5 min, median (range)	8 (4-10)
Gestational age in weeks, median (range)	39 (36.2-42.0)
Birthweight in grams, median (range)	3550 (2010-4175)

Abnormalities on the Child Behavior Checklist subscales included decreased attention (8/18), anxious (7/18), emotional (6/18), oppositional (6/18), withdrawn (6/18), affective problems (4/18), and pervasive difficulties (3/18). Three children (17%) tested positive on the Modified Checklist for Autism in Toddlers screening test for autistic spectrum disorders.

Relationship Between Cerebellar Injury and Neurodevelopmental Outcome

Children with large cerebellar lesions that resulted in cerebellar hemispheric atrophy, vermis atrophy, or both had significantly lower mean scores on the Mullen Scales of Early Learning gross motor, visual reception, and expressive language domains, as well as early learning composite scores, compared with those with small cerebellar lesions ($P < 0.05$ for all four subscales) (Table 4). There were no differences in fine motor and receptive language abilities between the two groups. Similarly, mean scores on the Vineland Adaptive Behavior Scale for communication, socialization, and mobility, as well as for externalizing and internalizing behavioral problems on the Child Behavior Checklist, were significantly higher in children with large cerebellar lesions ($P < 0.05$ for all), compared with those with small lesions. All three children who tested positive on the autism screening test (Modified Checklist for Autism in Toddlers) had atrophy of the superior cerebellar vermis.

Discussion

There was a broad spectrum of cerebellar injury and neurodevelopmental outcome in the present cohort of term-born infants. Specifically, common prenatal and perinatal characteristics were identified for these injuries: primiparity, group B streptococcus, maternal chronic conditions, abnormal fetal heart rate, instrument-assisted vaginal delivery, and emergency cesarean section. In this group of term infants with cerebellar injury, the lesions were primarily hemorrhagic, and the topographic distribution was more commonly focal, bilateral, and medial, or deep within the cerebellar hemispheres and superior vermis. A subgroup of children, however, exhibited more extensive cerebellar and vermis injury with atrophy.

The spectrum of functional neurodevelopmental sequelae in these children was similarly broad, extending well beyond the motor domain to include significant cognitive, language, behavioral, and social deficits. The topography of the structural MRI findings could be related to the functional outcome in these children.

The pathogenetic mechanisms for cerebellar injury in the term infant are almost certainly multifactorial in origin, with risk factors in maternal, intrapartum, and neonatal spheres. Clinical features noted with the development of cerebellar injury in the cohort were as follows. More than half of the mothers were primiparous, and more than a third were older than 35 years. Notably, 5/20 infants (25%) were the product of assisted conception, compared with a national annual rate of 1% of liveborn infants [13]. Recent studies have shown an association between the development of germinal matrix–intraventricular hemorrhage and cerebellar hemorrhage in the preterm infant and assisted conception [14-17].

Infection and inflammation have been implicated in the pathogenesis of fetal and neonatal brain injury [15,18,19]. In the present study, although 35% of mothers were group B streptococcus positive at the time of delivery, there was

Table 2. Cerebellar findings on initial magnetic resonance imaging studies (n = 20)

Imaging Characteristics	
Cerebellar hemorrhage, no. (%)	17 (85)
Bilateral, no.	7
Bilateral + vermis, no.	3
Unilateral right, no.	3
Unilateral right + vermis, no.	1
Unilateral left, no.	3
Cerebellar nonhemorrhagic infarction, no. (%)	3 (15)
Bilateral, no.	1
Unilateral right, no.	1
Unilateral left, no.	1
Associated posterior fossa, subarachnoid hemorrhage, no. (%)	4 (20)
Associated supratentorial abnormalities	12 (60)
Choroid plexus hemorrhage, no.	1
Germinal matrix hemorrhage (unilateral right), no.	1
Intraventricular hemorrhage, no.	4
Parenchymal hemorrhage, no.	3
Bilateral periatrial white matter, no.	1
Unilateral left temporal, no.	1
Unilateral right posterior corpus callosum, no.	1
Associated supratentorial subdural hemorrhage, no. (%)	4 (20)

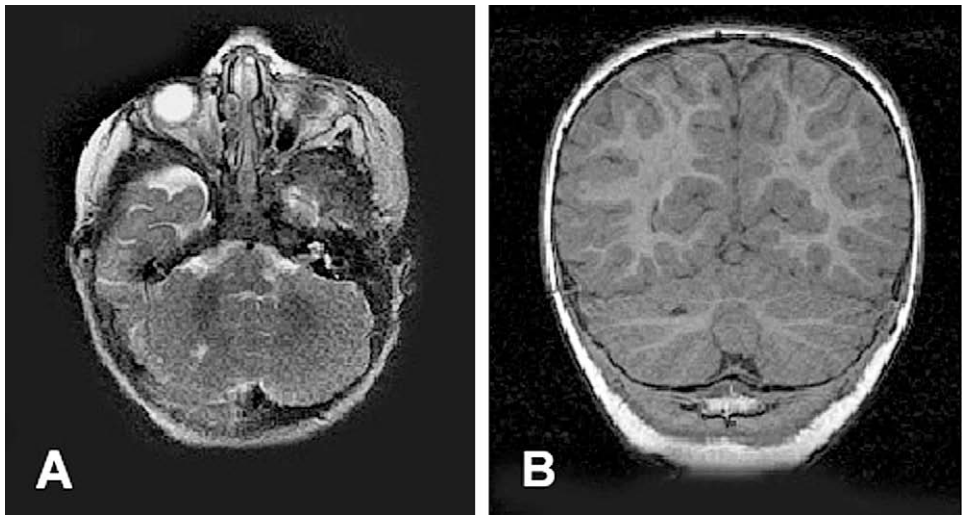

Figure 1. (A) Magnetic resonance imaging (MRI) at age 21 days. Axial T_2-weighted image (TR/TE = 2800/98 ms) shows a small, nonhemorrhagic focus of signal abnormality in the medial portion of the right cerebellar hemisphere. (B) Follow-up MRI at age 18 months. Coronal T_1-weighted spoiled gradient recalled echo image (TR/TE = 35/3 ms) indicates focal tissue loss at the gray matter–white matter junction in the right cerebellar hemisphere.

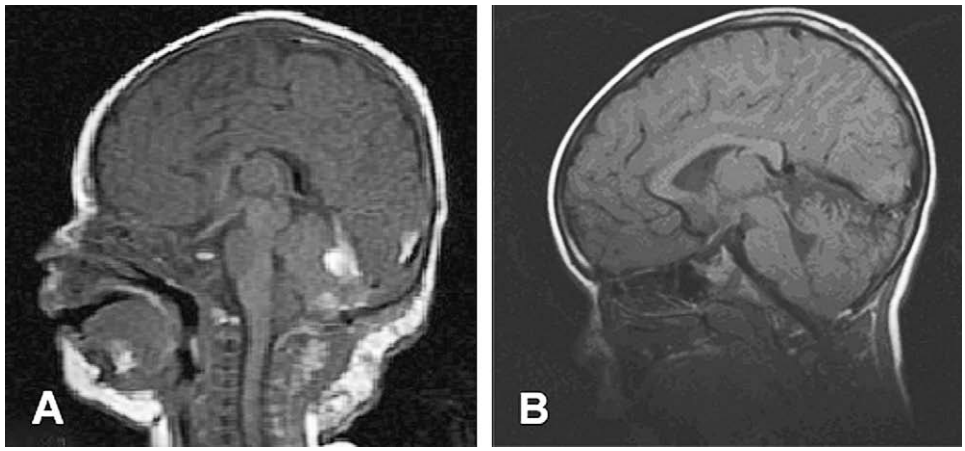

Figure 2. (A) MRI at age 6 days. Sagittal T_1-weighted image (TR/TE = 300/14 ms) reveals cerebellar vermis hemorrhage associated with small midline posterior fossa and occipital subdural hemorrhages. (B) Follow-up MRI at age 34 months. Sagittal T_1-weighted image (TR/TE = 450/14 ms) reveals atrophic changes with gliosis in the superior cerebellar vermis.

no significant relationship with neonatal infections. Furthermore, maternal conditions were also common in our cohort, including Factor V Leiden, multiple sclerosis, diabetes mellitus, Crohn's disease, and rheumatoid arthritis.

Intrapartum factors present in this cohort of infants with cerebellar injury included abnormalities in fetal heart rate tracings and instrument-assisted vaginal delivery in approximately one third of newborns, and the need for emergent cesarean section in one out of every four deliveries. Others have described a similar correlation between fetal distress and other forms of hemorrhagic brain injury in preterm infants [15,20,21].

As part of their clinical presentation, two thirds of infants with cerebellar injury developed apneic episodes and nearly one third developed clinical seizures (30%) within the first 36 hours after birth, prompting neuroimaging investigations and neurosurgical intervention in 25% of infants.

The topography of cerebellar injury in this cohort can be divided into two broad categories. The most common pattern consisted of small hemorrhages deep within the cerebellum, which were frequently bilateral and involved the vermis in approximately one quarter of cases. Of these small lesions, half were tiny punctuate lesions, such as those previously described in the supratentorial white matter of premature infants [22,23]. The finding of punctate cerebellar lesions in term infants is, to our knowledge, novel. The second category of cerebellar injury was similar to that previously described, namely large hemispheric and vermian hemorrhages, primarily medial and superior in location. Unlike the small lesions, these large cerebellar lesions were frequently associated with subsequent cerebellar hemispheric and vermis atrophy. In previous reports, these extensive hemispheric or vermis cerebellar lesions have been associated with hypoxic-ischemic encephalopathy,

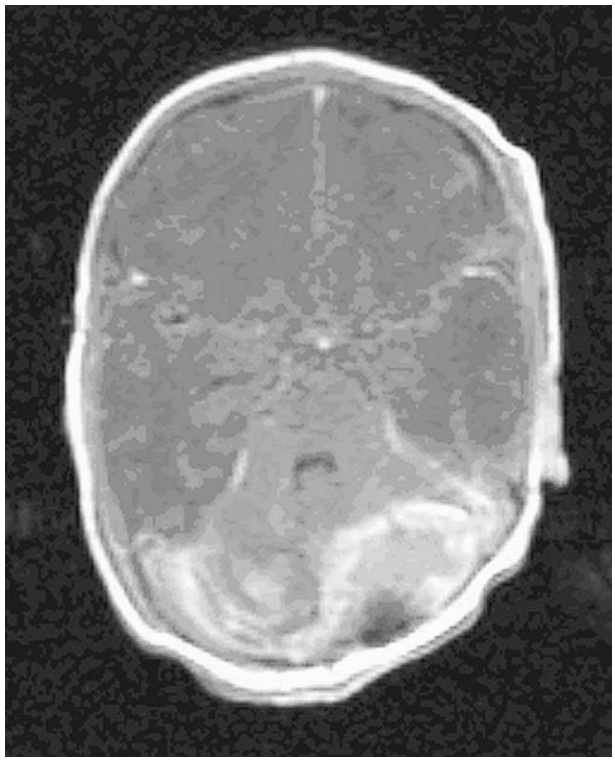

Figure 3. MRI at age 4 days. Axial T_1-weighted image (TR/TE = 450/8 ms) reveals a large extra-axial posterior fossa hemorrhage that also involves the posterior portions of the cerebellar hemispheres. The infant died in the neonatal period.

congenital or metabolic disorders, complex congenital heart disease, trauma, or extracorporeal membrane oxygenation [3,24-27].

The neurodevelopmental outcome of survivors of cerebellar injury was variable and ranged from normal to significant and wide-ranging disabilities. Overall, gross motor and expressive language deficits, as well as externalizing behavioral problems, were most prevalent among the various developmental domains. Factors associated with greater neurodevelopmental disabilities included the topography of the cerebellar injury and the presence of cerebellar hemispheric atrophy, vermis atrophy, or both. It is important to note that the range of follow-up of this cohort was broad, and that the prevalence of abnormal findings may be underrepresented.

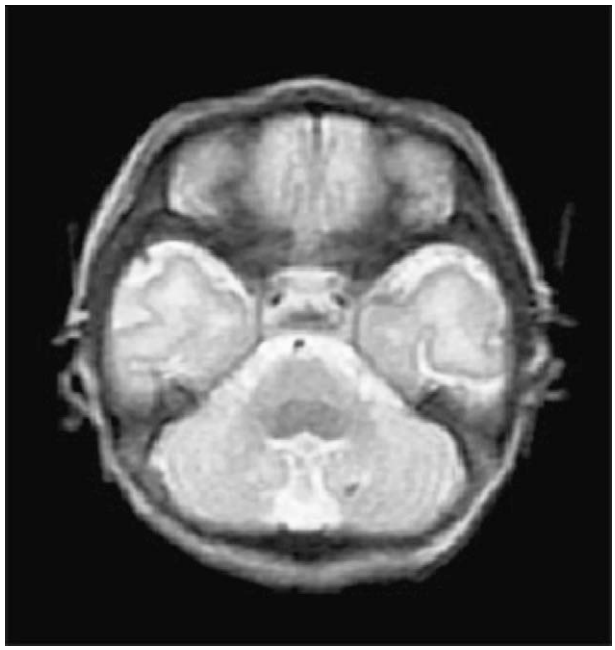

Figure 4. MRI at age 9 days. Axial T_2-weighted image (TR/TE = 4000/104 ms) reveals punctuate hemorrhage in the left medial portion of the cerebellar hemisphere.

Table 3. Developmental outcome of children with cerebellar hemorrhage at term birth (n = 18)

Outcome Measure	Mean ± S.D. (range)	Abnormal, no. (%)
Mullen Scales of Early Learning		
Gross motor	35.4 ± 11.6	8 (44)
Fine motor	45.8 ± 10.9	4 (22)
Visual reception	42.0 ± 12.5	6 (33)
Receptive language	38.2 ± 10.0	4 (22)
Expressive language	35.3 ± 11.3	8 (44)
Early learning composite	88.7 ± 12.2	5 (28)
Vineland Adaptive Behavior Scales		
Daily living	87.1 ± 11.3	4 (22)
Socialization	89.3 ± 10.5	5 (28)
Communication	82.5 ± 10.9	5 (28)
Motor	93.6 ± 9.4	4 (22)
Child Behavior Checklist		
Internalizing	48.1 ± 5.2	4 (22)
Externalizing	58.9 ± 4.1	8 (44)
Modified Checklist of Autism in Toddlers (M-CHAT)		
M-CHAT score	2 (0-6)	3 (17)

Abbreviation:
S.D. = Standard deviation

Despite the relatively small sample size, this is, to our knowledge, the largest series describing neurodevelopmental outcome in children surviving cerebellar injury after term birth. In fact, the long-term outcome of these children is poorly documented. Although there are reports of significant neurologic and cognitive deficits in this population [1,3,4,28], those studies did not use standardized outcome measures and based outcome largely on medical record reviews. Furthermore, the populations previously described appear to have had greater illness severity, more frequently requiring neurosurgical intervention, and a higher mortality than in the present cohort [1,4,6]. Also, outcomes in several studies were confounded by primary medical diagnoses such as congenital heart disease or metabolic disorders, in addition to the presence of cerebellar injury.

The present results suggest that cerebellar injury is primarily hemorrhagic, and that these lesions can be categorized into two distinct topographic distributions (small lesions vs large lesions, often in the superomedial hemispheres and vermis). The distinction is important, given the variability in the nature and severity of neurodevelopmental outcome

Table 4. Comparison of neurodevelopmental outcomes in children with small vs large cerebellar lesions at term birth

Outcome Measure	Cerebellar Lesion, mean ± S.D.		*P*-value
	Small (n = 11)	Large (n = 7)	
Mullen Scales of Early Learning			
Gross motor	39.5 ± 3.9	27.5 ± 5.9	0.01
Fine motor	40.8 ± 4.6	35.8 ± 5.2	0.15
Visual reception	41.0 ± 3.8	29.0 ± 4.7	0.03
Receptive language	38.2 ± 3.9	34.2 ± 4.6	0.34
Expressive language	35.3 ± 3.9	28.3 ± 4.5	0.02
Early learning composite	90.7 ± 4.8	82.5 ± 6.1	0.01
Vineland Adaptive Behavior Scales			
Daily living	91.1 ± 3.9	86.1 ± 4.7	0.08
Socialization	89.3 ± 4.5	82.3 ± 4.7	0.03
Communication	88.5 ± 3.9	81.3 ± 5.1	0.04
Motor	86.1 ± 4.4	79.3 ± 4.8	0.01
Child Behavior Checklist			
Internalizing	52.3 ± 5.2	60.1 ± 6.1	0.04
Externalizing	57.0 ± 4.1	65.9 ± 5.6	0.01
Modified Checklist of Autism in Toddlers (M-CHAT)			
M-CHAT score	0	3	0.08

Large lesions: ≥1 cm, with cerebellar atrophy, vermis atrophy, or both.
Abbreviation:
S.D. = Standard deviation

described for these two categories. However, the small sample size precluded more targeted statistical analyses comparing the neurodevelopmental outcome between ischemic and hemorrhagic lesions, the influence of supratentorial parenchymal injury on outcome, or the difference in outcome between punctate and other small lesions.

There is accumulating evidence in recent literature for a fundamental role of the cerebellum in cognition, language, and affect in adults and adolescents with cerebellar tumors, and more recently in preterm infants after cerebellar hemorrhagic injury [29-34]. The results of the present study corroborate these findings in term infants with cerebellar injury. The extent and severity of cognitive, language, behavioral, and social deficits appear to be less pronounced in term infants, however, and largely dependent on the size and topography of the lesions.

Reports from parallel studies have recently described a high prevalence of positive screening for early autistic features in survivors of extreme preterm birth [35], and in particular those with cerebellar injury [33]. In the present study, three children tested positive on autism screening tests performed at follow-up (Modified Checklist for Autism in Toddlers); all three of these children had acute vermian injury and subsequent superior vermian atrophy documented at follow-up MRI. These findings corroborate previous data from the authors' group and others [33,36-38] suggesting an important role for the vermis in regulating social and emotional development. This relationship merits further exploration.

In summary, the detailed long-term outcome of term infants with cerebellar injury can be related to two distinct topographic patterns of injury. The spectrum of disability in survivors is wide ranging and often includes motor, cognitive, language, behavioral, and social deficits. Ongoing surveillance of neurodevelopmental progress is clearly warranted in this high-risk group of infants and should encompass global developmental screening at key developmental intervals.

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