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Cranial Ultrasound Lesions in the NICU Predict Cerebral Palsy at Age 2 Years in Children Born at Extremely Low Gestational Age

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Abstract

Our prospective cohort study of extremely low gestational age newborns evaluated the association of neonatal head ultrasound abnormalities with cerebral palsy at age 2 years. Cranial ultrasounds in 1053 infants were read with respect to intraventricular hemorrhage, ventriculomegaly, and echolucency, by multiple sonologists. Standardized neurological examinations classified cerebral palsy, and functional impairment was assessed. Forty-four percent with ventriculomegaly and 52% with echolucency developed cerebral palsy. Compared with no ultrasound abnormalities, children with echolucency were 24 times more likely to have quadriparesis and 29 times more likely to have hemiparesis. Children with ventriculomegaly were 17 times more likely to have quadriparesis or hemiparesis. Forty-three percent of children with cerebral palsy had normal head ultrasound. Focal white matter damage (echolucency) and diffuse damage (late ventriculomegaly) are associated with a high probability of cerebral palsy, especially quadriparesis. Nearly half the cerebral palsy identified at 2 years is not preceded by a neonatal brain ultrasound abnormality.

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Keywords

cerebral palsy; extremely low gestational age; cranial ultrasound

Cranial ultrasound studies are used both to identify acute cerebral events in newborns and to assist with prognosis of motor and cognitive dysfunctions. For example, white matter damage, most often identified by a cranial ultrasound abnormality, is the single strongest predictor of cerebral palsy.[1–11] One limitation of many previous prognostic studies of neonatal ultrasound lesions is the reliance on a single sonologist to interpret scans. Because of the inherent variability in interpreting cranial sonograms, multiple readers may increase reliability.[12] Another limitation of previous prognostic studies is the lack of replicable operational definitions of cerebral palsy and its types.[1–11,13–19]

In this article, we report how well cranial ultrasound scans obtained in the neonatal intensive care unit predicted cerebral palsy types and severity of motor dysfunction when children were 2 years old, corrected age. Our study of 1053 children born before the 28th postmenstrual week differs from previous studies in several ways. First, the protocol scans of these children were read by at least 2 independent sonologists for congruence about major abnormalities including intraventricular hemorrhage, moderate/severe ventriculomegaly, echogenic lesion, and echolucent lesion. Second, the sonologists' evaluation included specifically information about the location, extent, and laterality of these lesions. Third, the children were given a standardized neurological examination; the standardization of the examination resulted in a low inter-observer variability for interpretation of examination findings.[20] Fourth, those performing the clinical exam were blinded to, and thus not biased by, ultrasound findings. Fifth, we created a cerebral palsy computer-driven diagnostic algorithm, which standardized the diagnosis of topography-based types of cerebral palsy.[21]

Methods

The ELGAN Study

The ELGAN study was designed to identify characteristics and exposures that increase the risk of structural and functional neurologic disorders in extremely low gestational age newborns. During the years 2002–2004, women delivering before 28 weeks gestation at 1 of 14 participating institutions in 11 cities in 5 states were asked to enroll in the study. The individual institutional review boards approved the enrollment and consent processes.

Mothers were approached for consent either upon antenatal admission or shortly after delivery, depending on clinical circumstance and institutional preference, and 1249 mothers of 1506 infants consented (Figure 1). Approximately 260 women were either missed or did not consent to participate.

Eighty-eight percent (1053/1198) of eligible children were examined at close to 24 months postterm equivalent.

Imaging Protocol

Routine ultrasound examinations were performed by technologists at all of the hospitals using digitized high frequency transducers (7.5 and 10 MHz or higher). Ultrasound examinations always included as a minimum 6 standard coronal and 5 parasagittal views using the anterior fontanel as the sonographic window.[22] Mastoid views were not routinely obtained.

Of the 1506 infants enrolled, 1455 had at least 1 protocol ultrasound scan set and, of these, 1053 were examined at 2 years corrected age (Figure 1). The 3 sets of protocol scans were

defined by the postnatal day on which they were obtained. Protocol 1 scans were obtained between the first and fourth day (N = 795); protocol 2 scans were obtained between the fifth and fourteenth day (N = 981), and protocol 3 scans were obtained between the 15th day and the 40th postconceptual week (N = 1016). 722 had all 3 sets of ultrasound studies.

Reading Procedures

Several methods were employed to minimize observer variability. A standard data collection form was developed, which included templates for evaluating ventricular size, parenchymal injury, and intraventricular hemorrhage. A manual with definitions and instructions was distributed. Lastly, a "dry run" review of a series of cases was performed during a conference call to discuss differences in interpretation.[12]

Each ultrasound examination was first read by a study sonologist at the institution of the infant's birth. The images were sent to a sonologist at another ELGAN study institution for a second reading, usually embedded on a compact disc (eFilm Workstation TM, Merge Healthcare/ Merge eMed, Milwaukee, Wisconsin) although occasionally as digitized film. The eFilm program also provided options to adjust and enhance the studies the original reader had done, including the ability to zoom and alter contrast and brightness. Clinical information was not available to either the initial or secondary interpreter.

If there was discrepancy regarding the recognition of intraventricular hemorrhage, moderate/ severe ventriculomegaly, echogenicity, or echolucency, the images were sent to a third (tie-breaking) reader who was blind to what the previous readers reported. Because interobserver variability for echogenic lesions was high[12] and because transient echogenicities were shown not to be predictive of poor outcome,23 the following analyses focus on intraventricular hemorrhage, ventriculomegaly, and echolucency.

Sixteen white matter zones in each hemisphere were evaluated for echogenicity and echolucency. The data collection did not require a diagnosis to accompany these lesions, nor were criteria provided for any diagnosis. Rather, the sonologist was free to apply the labels of cystic periventricular leukomalacia, and periventricular hemorrhagic infarction as deemed appropriate, beyond the observations of echogenicity, echolucency, intraventricular hemorrhage, and ventriculomegaly that were mandated for all. Congruence for periventricular leukomalacia and periventricular hemorrhagic infarction diagnosis was not undertaken.

Cerebral Palsy

The neurological examiners studied a manual, a data collection form and an instructional compact disc designed to minimize examiner variability. Subsequently, they demonstrated acceptably low variability.[20] The diagnosis of cerebral palsy type (quadriparesis, hemiparesis, and diparesis) was based on an algorithm using these data.[21]

Gross Motor Functional Classification Scale

The neurological examiners rated each child based on the Gross Motor Function Classification System. All children with a Gross Motor Functional Classification System of 2 or higher had a cerebral palsy diagnosis, and are classified here as having more severe cerebral palsy.

Data Analysis

The null hypothesis was that no ultrasound lesion predicts cerebral palsy occurrence, cerebral palsy severity, or cerebral palsy type. The primary ultrasound lesions evaluated were intraventricular hemorrhage, ventriculomegaly, and echolucency. The lesion characteristics included location, specifically anterior and posterior locations, extent as measured by the number of anatomic locations involved, unilateral or bilateral involvement, and identification

of what sonologists called periventricular hemorrhagic infarction and periventricular leukomalacia. Cerebral palsy types included quadriparesis, hemiparesis, and diparesis, and cerebral palsy severity was determined according to Gross Motor Functional Classification System categorization.

We present row percents in most tables to show the proportion of children with a particular ultrasound lesion who had each type of cerebral palsy and the associated degree of impairment. Using cerebral palsy type and severity as the outcomes of interest, we evaluated the sensitivities, specificities, and predictive values of ventriculomegaly and echolucency seen on head ultrasound study in the neonatal period.

Results

Overview (Table 1–Table 3)

Eleven and a half percent of all children in our sample were given a diagnosis of cerebral palsy at approximately 2 years corrected age. The risk of cerebral palsy was 9% if the scan had isolated intraventricular hemorrhage, similar in prevalence to that observed among children with completely normal head ultrasound studied (6%). Forty-three percent (51/120) of children with cerebral palsy had normal cranial ultrasound studies (Table 1 and Table 2). In contrast, 34% of those whose scan had isolated echolucency in the cerebral white matter and 39% of those whose scan had isolated ventriculomegaly developed cerebral palsy (Table 1). Ultrasound lesions, however, tend not to occur in isolation. For example, 87% of scans with ventriculomegaly and 62% of scans with intraventricular hemorrhage had an additional lesion (Table 2).

Among children who had ventriculomegaly or echolucency, the risk of quadriparesis was 3 to 5 times higher than the risk of diparesis. In contrast, among those with no head ultrasound study abnormality, the risk of quadriparesis and diparesis were comparable (Table 1). Viewed differently, 34% (22/64) of children who developed quadriparesis and 60% (22/37) of children who developed diparesis did not have intraventricular hemorrhage, echolucency, or ventriculomegaly (Table 2). Nearly half of those with cerebral palsy had a Gross Motor Functional Classification System of 2 or greater, and 85% of these children had quadriparesis.

Hemorrhage (Table 3)

Nine percent of children who had a unilateral intraventricular hemorrhage and 28% of children who had bilateral intraventricular hemorrhage developed cerebral palsy. Also, blood in the third and fourth ventricles, a correlate of ventriculomegaly, predicted quadriparesis better than blood in the lateral ventricle. Of the 10 children who had bilateral cerebellar hemorrhages, 3 developed quadriparesis and 3 developed hemiparesis.

Moderate/Severe Ventriculomegaly (Table 4)

Early studies (examinations performed during the first 14 postnatal days)—Of children who had unilateral ventriculomegaly, 21% developed hemiparesis and 7% developed quadriparesis. In contrast, those who had bilateral ventriculomegaly were more likely to develop quadriparesis than hemiparesis (23% versus 6%). Diparesis occurred in 13% to 14% of children with ventriculomegaly, whether unilateral or bilateral.

Late studies (examinations performed between postnatal day 15and expected date of confinement)—Ventriculomegaly on the third protocol scan was a better predictor of cerebral palsy than ventriculomegaly on an early scan. For example, the rate of cerebral palsy among the 19 subjects who had early ventriculomegaly, but never had late ventriculomegaly, was 21% (5% with quadriparesis, 5% with hemiparesis, and 11% with

diparesis; data not shown), compared to 50% of children with ventriculomegaly on a late scan. Unlike early unilateral ventriculomegaly, late unilateral ventriculomegaly predicted quadriparesis even better than it predicted hemiparesis. Nearly half of those with bilateral late ventriculomegaly had the quadriparetic form of cerebral palsy and a third had more severe impairment (Gross Motor Functional Classification System >2). Diparesis occurred in less than 8% of cases among those with late ventriculomegaly regardless of location or laterality of the ventricular enlargement.

Laterality of Echolucent Lesions and Empiric Diagnoses

Seventy-one children had an echolucency on head ultrasound study, and one third with a unilateral lesion and two thirds with bilateral lesions developed cerebral palsy. Unilateral lesions predicted similar rates of quadriparesis and hemiparesis (17% and 15%), whereas bilateral lesions were 7 to 13 times more likely to predict quadriparesis. Diparesis occurred in only 4% of those with either unilateral or bilateral echolucency.

Approximately 45% of children whose scan was given a diagnosis of cystic periventricular leukomalacia or periventricular hemorrhagic infarction developed cerebral palsy, which, in over 60% of cases, was classified as quadriparesis. Less than a third of those with cerebral palsy and periventricular hemorrhagic infarction, which is a predominantly unilateral lesion, had hemiparesis. Fewer yet with either periventricular hemorrhagic infarction (19%) or cystic periventricular leukomalacia (28%) had Gross Motor Functional Classification System level of 2 or greater.

Extent of Echolucent Lesions

Each hemisphere was divided into 16 zones on the ultrasound data collection form. Although no linear trend was seen between the number of zones involved and the risk of cerebral palsy, cerebral palsy type or severity, 85% of the 13 children whose scan had 5 or more echolucency zones developed cerebral palsy.

Location of Echolucent Lesions

Only 5 children with diparesis had echolucency and none of the lesions were seen in posterior regions. The echolucency lesions seen in hemiparetics and quadriparetics were seen equally frequently in the anterior and posterior aspects of the cerebral hemispheres. Those with hemiparesis were more than twice as likely to have unilateral lesions as bilateral lesions, whereas those with quadriparetics were more than 3 times more likely to have bilateral lesions as unilateral lesions (data not shown).

Infants deemed to have cystic periventricular leukomalacia were as likely to have echolucency lesions placed anteriorly as placed posteriorly. Among scans with periventricular hemorrhagic infarction, echolucency lesions were more likely to occur anteriorly. More than half of scans with periventricular hemorrhagic infarction also had lesions along the more posteriorly placed body of the lateral ventricles.

Ultrasound Lesions as Predictors of Cerebral Palsy (Table 5 and Table 6)

Echolucency, ventriculomegaly, and intraventricular hemorrhage were strongly and significantly associated with quadriparesis (risk ratio: 24, 17, 5.1) and hemiparesis (risk ratio: 29, 17, and 5.8). Diparesis also was significantly associated with all 3 head ultrasound study findings, but less strongly (risk ratio: 5, 5.7, and 2.3).

Among infants with ventriculomegaly, 44% developed cerebral palsy, and among infants with echolucency, 52% developed cerebral palsy (positive predictive value). Ventriculomegaly and echolucency predicted more severe cerebral palsy (Gross Motor Functional Classification

System of 2 or greater) and quadriparesis in approximately half of children with cerebral palsy. For quadriparesis and hemiparesis, the sensitivity of ventriculomegaly and echolucency ranged from 38 to 47%, whereas for diparesis it was 14 and 24%. All negative predictive values and specificities were 92% or higher.

Discussion

Overview

Based on our knowledge, this is the largest study to date relating neonatal cranial ultrasound findings and cerebral palsy at 2 years in extremely low gestational age neonates. We reject the null hypothesis that specific lesions do not predict specific types or severity of cerebral palsy. In general, the primary finding reported here is that about half the children with ventriculomegaly or echolucency developed cerebral palsy, and half of these children developed more severe cerebral palsy. Additionally, almost half of all children with cerebral palsy had an entirely normal head ultrasound study. Children with isolated intraventricular hemorrhage were only slightly more likely to have cerebral palsy than those with a normal head ultrasound study. Late occurrence of ventriculomegaly, bilateral echolucency, and identification of periventricular hemorrhagic infarction or periventricular leukomalacia were particularly predictive of quadriparesis. In contrast to children with normal head ultrasound study whose risk of quadriparesis and diparesis were comparable, children with abnormal head ultrasound study findings were 3 to 5 times more likely to have quadriparesis than diparesis. Finally, a diagnosis of periventricular hemorrhagic infarction was twice as likely as a diagnosis of cystic periventricular leukomalacia to predict hemiparesis, while cystic periventricular leukomalacia was twice as likely to predict quadriparesis as hemiparesis.

Head Ultrasound-Cerebral Palsy Associations

Hemorrhage—Isolated intraventricular hemorrhage or echogenic lesions predicted cerebral palsy only slightly better than scans without any abnormality, an observation made previously.[19,24,25] Yet, over a third of the infants with intraventricular hemorrhage developed cerebral palsy, which we attribute to the presence of associated echolucency and/or ventriculomegaly, indicators of white matter damage[26] and independent predictors of cerebral palsy. Of the 10 infants with bilateral cerebellar hemorrhage, 6 had cerebral palsy, an association reported previously.[27–30] Cerebellar hemorrhage was identified in a total of 14 infants, which may be an underestimate of true prevalence because mastoid views were not routinely obtained.

Severity—Overall, nearly half the children with cerebral palsy were more severely affected, defined by having a Gross Motor Functional Classification System of 2 or greater, comparable to other studies looking at cohorts born at comparable gestational age.[31,32] Nearly all children with more severe cerebral palsy had quadriparesis and most children with quadriparesis had more severe cerebral palsy. Compared to those without head ultrasound study abnormalities, children who had either ventriculomegaly or echolucency were 11 to 16 times more likely to have a Gross Motor Functional Classification System grade of 2 or greater and 17 to 24 times more likely to have quadriparesis. Those with diparesis were least likely to be more severely involved, also comparable to findings by others.[32] The importance of distinguishing those with quadriparesis and/or more severe forms of cerebral palsy is underscored by the observation in our cohort that these children have a markedly elevated risk of having microcephaly and cognitive impairment and for screening positive on the Modified Checklist for Autism in Toddlers.[21]

As others have shown, the presence of more than 1 abnormal ultrasound feature generally increased the risk of developing quadriparesis or more severe forms of cerebral palsy.[5] On the

other hand, once an echolucency was identified in our cohort, the risk of more severe cerebral palsy was not increased with additional abnormal ultrasound features.

Echolucent lesions and ventriculomegaly—Our findings that echolucency and ventriculomegaly are associated with subsequent cerebral palsy and that about one half of children with cerebral palsy have one or both of these abnormalities, are comparable to the findings of others. [9,11,19,31,33–37] Compared to children with no head ultrasound study abnormalities, children who had echolucency were 24 times more likely to have quadriparesis, 29 times more likely to have hemiparesis, and 5 times more likely to have diparesis. The advantages of our study include late imaging for 1016 of 1053 subjects, agreement about abnormalities by 2 or 3 independent readers of ultrasound studies by individuals and had no knowledge of the clinical history, and implementation of a standardized method of identifying cerebral palsy.

Compared to children with no head ultrasound study abnormalities, children who had ventriculomegaly were 17 times more likely to have quadriparesis and hemiparesis and nearly 6 times more likely to have diparesis. Ventriculomegaly identified closer to term appears to be more predictive of cerebral palsy than the presence of ventriculomegaly seen within the first 2 weeks of life. Conversely, those who had ventriculomegaly early, but did not demonstrate ventriculomegaly on late scans had rates of quadriparesis that were comparable to those without ventriculomegaly. The importance of late ventriculomegaly as a predictor of later disability was emphasized by Ment, who reported a 45% risk for cerebral palsy (and a 55% risk for mental retardation) among those that had ventriculomegaly at term.[13] This observation may relate to lost white matter volume as a contributor to late ventriculomegaly in contradistinction to transient, early ventricular enlargement due to the presence of intraventricular blood.

Cerebral palsy in children who have no head ultrasound study abnormality—Six percent of children whose scan was entirely normal developed cerebral palsy accounting for nearly half of those with cerebral palsy. Others have also shown that among extremely low birth weight infants, those with normal cranial ultrasound studies still carry a risk as high as 9% for cerebral palsy.[14,16]

Children who develop cerebral palsy and have no abnormality on any ultrasound scan of the head might well have lesions below sonographic resolution,[36,38–41] an explanation that has been called the “tip of the iceberg” hypothesis.[42] Some of these may first become evident on ultrasound studies performed near term, as the brain grows,[36,39,43–46] while some can be identified on routine or specialized magnetic resonance imaging studies, such as diffusion tensor imaging and volumetric evaluation. [41,47–49] Studies of infants using both ultrasound and magnetic resonance imaging[40,50] or ultrasound and post-mortem examination,[32] show that white matter damage identified on sonograms is a relatively small proportion of the damage evident on magnetic resonance or by pathology.

Periventricular hemorrhagic infarction and periventricular leukomalacia—The name periventricular hemorrhagic infarction is applied to largely unilateral or very asymmetric lesions.[51] Indeed, children who had periventricular hemorrhagic infarction were twice as likely to have hemiparesis as quadriparesis, which affirms previous reports by Bassan et al.[52] Those with hemiparesis were more likely to have unilateral ventriculomegaly or periventricular hemorrhagic infarction than other lesions on head ultrasound study. Also, 60% of those with periventricular hemorrhagic infarction had bilateral disease manifesting as diparesis or quadriparesis, a finding also noted by Bassan et al.[52]

In contrast to periventricular hemorrhagic infarction, periventricular leukomalacia is more often associated with diparesis.[51,53] Yet, those deemed to have cystic periventricular

leukomalacia in this cohort were more than twice as likely to have quadriparesis and hemiparesis as diparesis.

Limitations and Strengths of the Study

Limitations of the study: head ultrasound study and cranial magnetic resonance imaging findings—Perhaps the main limitation of this study is our dependence on ultrasound to identify white matter damage. Magnetic resonance imaging studies are more sensitive, especially of diffuse white matter damage.[36,37] In cohorts of infants born at less than 30 weeks gestation, magnetic resonance imaging sensitivity [36,37] and positive predictive value[36] are more than double that reported using head ultrasound study. Thus, our study might misclassify some infants as not having white matter damage, when, indeed, a magnetic resonance imaging would identify such damage. Mastoid views were not routinely employed, which may lead to an underestimation of cerebellar lesions.

Strengths of the study—Strengths of the current study include the large sample[54] based on gestational age,[55] minimized interobserver disagreements about ultrasound findings,[12] standardized diagnosis of cerebral palsy,[21] minimized clinical bias by examiners, and the use of high frequency ultrasounds, which were obtained in most after the first month of life, usually close to term, when white matter damage might be seen for the first time in infants with previously normal scans.[9]

Conclusions and Inferences

Echolucency or ventriculomegaly on head ultrasound study studies are the strongest newborn predictor of subsequent cerebral palsy, especially quadriparesis and more severe cerebral palsy. Yet, nearly half of children who are destined to have cerebral palsy, like many extremely low gestational age newborns who have substantial development disorders, do not have an abnormality on neonatal head ultrasound study studies. These children with cerebral palsy and no recognized head ultrasound study abnormality are at lower risk for quadriparesis and more severe forms of cerebral palsy than children with ventriculomegaly or echolucency. Some, but not all, infants destined to develop cerebral palsy who had normal head ultrasound study have morphologic abnormalities seen on magnetic resonance imaging performed near term. It is unsettled whether magnetic resonance imaging would have been abnormal sooner after birth and whether there is an on-going process that accounts for further changes later that may be amenable to prevention or interruption. Although awaiting a more sensitive method for early identification of extremely low gestational age newborns who will develop cerebral palsy, clinicians should routinely assess these infants' neuromotor status after discharge from intensive care.

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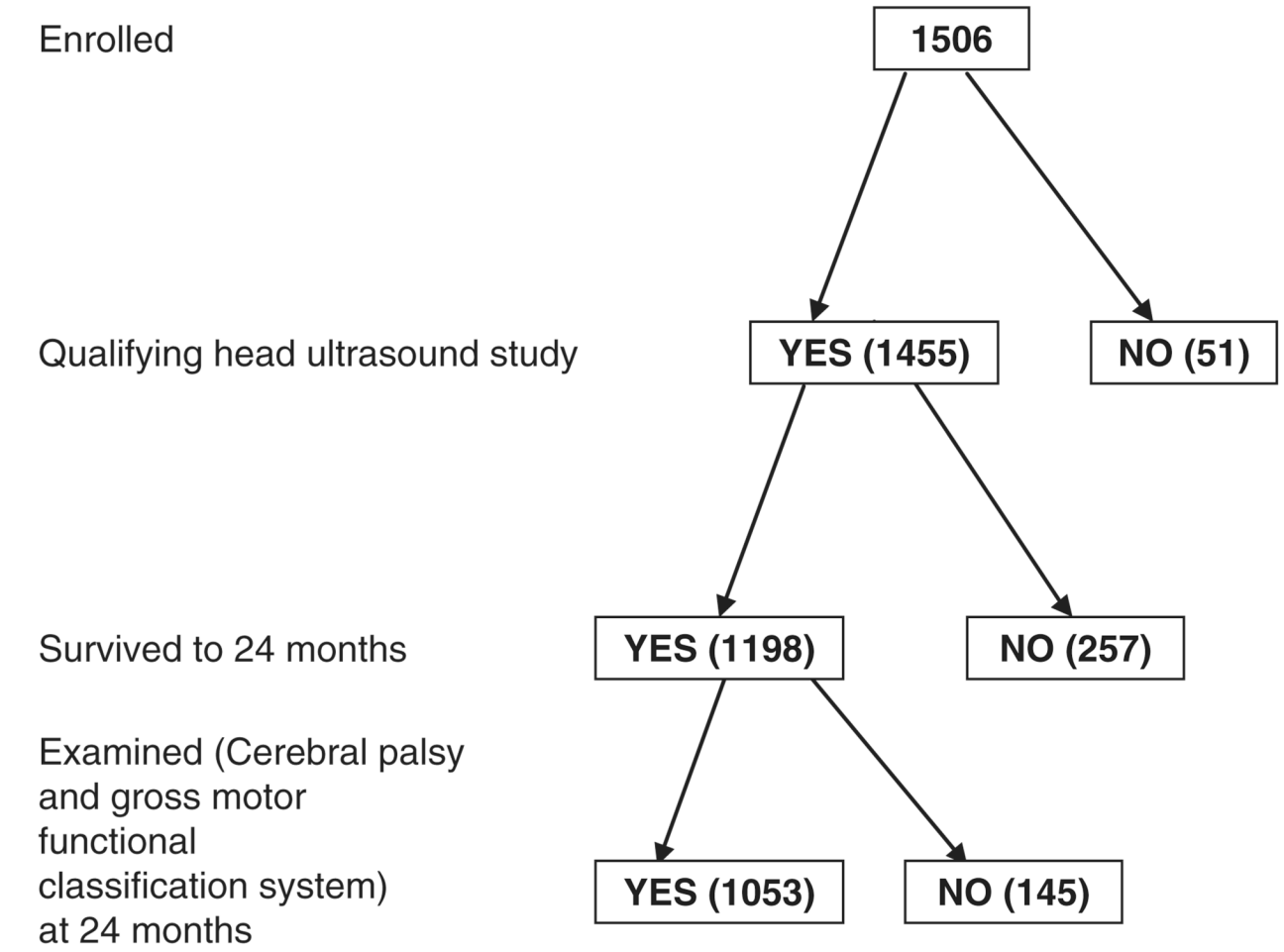

Figure 1.
Sample Description.

Table 1

The Percent of Children Who Had the Ultrasound Lesion Listed on the Left Who Developed the Cerebral Palsy Type or Severity Rating Listed at the Head of Each Column. These Are Row Percents (ie, the percent of an item with a particular characteristic listed in the left-most column that occurs in each subsequent column heading).

	Cerebral Palsy and Dysfunction Severity					
	Quadriparesis	**Diparesis**	**Hemiparesis**	**No CP**	**GMFCS ≥ 2**	**N**
IVH	13	6	5	77	11	217
VM	27	9	9	56	22	105
EG lesion	18	4	7	70	14	138
EL lesion	33	7	12	48	29	73
IVH only	4	4	1	90	2	93
VM only	23	8	8	62	8	13
EG only	2	6	0	92	2	48
EL only	24	5	5	67	29	21
No lesion	3	3	1	94	2	739
Single lesion						175
Multiple lesions						139
Maximum N	64	37	19	933	55	1053

Abbreviations: CP, cerebral palsy; IVH, intraventricular hemorrhage; VM, ventriculomegaly; EG, echogenicity; EL, echolucency; GMFCS, gross motor function classification system.

Table 2

The Percent of Children Who Had Each Combination of Ultrasound Lesions Listed on the Left Who Developed the Cerebral Palsy Type or Severity Rating Listed at the Head of Each Column. These are row percents.

US Abnormality				Cerebral Palsy and Dysfunction Severity					
IVH	VM	EG	EL	Quadriparesis	Diparesis	Hemiparesis	No CP	GMFCS ≥ 2	N
+	+	+	+	45	5	27	23	27	22
+	+	+	−	25	5	5	65	25	20
+	+	−	+	0	67	0	33	0	3
+	+	−	−	17	10	0	74	19	42
+	−	+	+	20	0	10	70	20	10
+	−	+	−	4	0	4	92	0	24
+	−	−	+	0	0	0	100	0	3
+	−	−	−	4	4	1	90	2	93
−	+	+	+	67	0	33	0	67	3
−	+	+	−	0	0	0	100	0	1
−	+	−	+	100	0	0	0	100	1
−	+	−	−	23	8	8	62	8	13
−	−	+	+	40	10	0	50	40	10
−	−	+	−	2	6	0	92	2	48
−	−	−	+	24	5	5	67	29	21
−	−	−	−	3	3	1	94	2	739
Number				64	37	19	933	55	1053

Abbreviations: US, ultrasound; CP, cerebral palsy; IVH, intraventricular hemorrhage; VM, ventriculomegaly; EG, echogenicity; EL, echolucency; GMFCS, gross motor function classification system.

Table 3

The Percent of Infants Whose Scan Had a Hemorrhage (probable or definite) in the Location Listed on the Left, Who Were Also Given the Cerebral Palsy Diagnosis or Severity Rating at the Top of Each Column. These are Row Percents.

	Cerebral Palsy and Dysfunction Severity					
Hemorrhage	**Quadriparesis**	**Diparesis**	**Hemiparesis**	**No CP**	**GMFCS ≥ 2**	**N**
Lateral ventricle						
Unilateral	4	1	4	91	4	81
Bilateral	16	6	5	72	12	140
Third ventricle	23	8	7	62	20	71
Fourth ventricle	28	6	6	59	22	32
Cerebellar						
Unilateral	0	0	0	100	0	4
Bilateral	30	0	30	40	40	10
Maximum N	64	37	19	930	55	1050

Abbreviations: CP, cerebral palsy; GMFCS, gross motor function classification system.

Table 4

The Percent of Infants Whose Scan Had Ventriculomegaly (moderate or severe) Identified Either on the First or Second Study (early scan) or on the Third Study (late scan) Unilaterally or Bilaterally, Who Were Also Given the Cerebral Palsy Diagnosis or Severity Rating at the Top of Each Column. These are Row Percents.

	Cerebral Palsy Diagnosis and Dysfunction Severity					N
	Quadriparesis	Diparesis	Hemiparesis	No CP	GMFCS ≥ 2	
Early scan						
Unilateral	7	14	21	57	14	14
Bilateral	23	13	6	58	16	31
N	63	37	19	921	54	1040
Late scan						
Unilateral	25	13	19	44	6	16
Bilateral	45	6	6	43	35	51
N	64	36	19	897	55	1016

Abbreviations: CP, cerebral palsy; GMFCS, gross motor function classification system.

Table 5

Risk Ratios and Their 95% Confidence Intervals for Each Cerebral Palsy Diagnosis and for a Gross Motor Function Classification Scale (GMFCS) of 2 or Higher Associated With Each Ultrasound Lesion or Diagnosis. The Referent Group for Each Ultrasound Lesion or Diagnosis Consists of Children Who Had*None*of the Lesions or Diagnoses While Children With Lesions and/or Diagnoses May Have Other Lesions or Diagnoses. The Models Are Adjusted for Gestational Age (23–24, 25–26, 27 weeks).

		Cerebral Palsy Diagnosis			
		Quadriparesis	**Diparesis**	**Hemiparesis**	**GMFCS ≥2**
Ultrasound lesion	IVH	5.1 (2.8, 9.6)	2.3 (1.1, 5.0)	5.8 (2.1, 17)	4.2 (2.1, 8.1)
	VM	17 (8.6, 32)	5.7 (2.4, 14)	17 (5.7, 49)	11 (5.5, 21)
	EL	24 (12, 48)	5.0 (1.7, 15)	29 (10, 86)	16 (7.6, 32)
Diagnosis	Early PVL	1.4 (.6, 3.5)	1.3 (.4, 3.9)	2.7 (.7, 10)	1.3 (.5, 3.4)
	Cystic PVL	14 (6.1, 30)	5.7 (1.8, 18)	12 (2.9, 48)	12 (5.3, 25)
	PVHI	9.6 (4.7, 20)	2.4 (.7, 8.6)	21 (7.2, 59)	4.9 (2.3, 11)

Abbreviations: IVH, intraventricular hemorrhage; VM, ventriculomegaly; EL, echolucency; GMFCS, gross motor function classification system; PVL, periventricular leukomalacia; PVHI, periventricular hemorrhagic infarction.

Table 6

Measures of the Ability of Head Ultrasound Abnormalities Evident Before Discharge From the Neonatal Intensive Care Unit to Predict a Cerebral Palsy Diagnosis at 24 Months Corrected Age.

Ultrasound Lesion	Ventriculomegaly					Echolucent Lesion				
Cerebral palsy	**QP**	**DP**	**HP**	**Any CP**	**GMF 2+**	**QP**	**DP**	**HP**	**Any CP**	**GMF 2+**
PVP	32	13	13	44	22	41	13	20	52	29
PVN	96	97	99	92	97	96	97	99	92	97
Sensitivity	44	24	47	38	42	38	14	47	32	38
Specificity	94	94	94	94	92	96	96	96	96	95

Abbreviations: QP, quadriparesis; DP, diparesis; HP, hemiparesis; PVP, predictive value positive; PVN, predictive value negative; CP, cerebral palsy.