Maternal or neonatal infection: association with neonatal encephalopathy outcomes

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BACKGROUND: Perinatal infection may potentiate brain injury among children born preterm. The objective of this study was to examine whether maternal and/or neonatal infection are associated with adverse outcomes among term neonates with encephalopathy.

METHODS: This study is a cohort study of 258 term newborns with encephalopathy whose clinical records were examined for signs of maternal infection (chorioamnionitis) and infant infection (sepsis). Multivariate regression was used to assess associations between infection, pattern, and severity of injury on neonatal magnetic resonance imaging, as well as neurodevelopment at 30 mo (neuromotor examination, or Bayley Scales of Infant Development, second edition mental development index <70 or Bayley Scales of Infant Development, third edition cognitive score <85).

RESULTS: Chorioamnionitis was associated with lower risk of moderate–severe brain injury (adjusted odds ratio: 0.3; 95% confidence interval: 0.1–0.7; $P = 0.004$) and adverse cognitive outcome in children when compared with no chorioamnionitis. Children with signs of neonatal sepsis were more likely to exhibit watershed predominant injury than those without ($P = 0.007$).

CONCLUSION: Among neonates with encephalopathy, chorioamnionitis was associated with a lower risk of brain injury and adverse outcomes, whereas signs of neonatal sepsis carried an elevated risk. The etiology of encephalopathy and timing of infection and its associated inflammatory response may influence whether infection potentiates or mitigates injury in term newborns.

Neonatal encephalopathy, presumed due to hypoxia–ischemia, occurs in 1–3 per 1,000 term births (1,2) and is a major cause of mortality and neurologic disability. Risk factors for adverse outcome include severity of the initial insult (3), abnormal electroencephalogram or severity of clinical encephalopathy and seizures (4,5), as well as pattern and severity of injury on magnetic resonance imaging (MRI) (6,7). Modifiable risk factors include hyperthermia and hypoglycemia (8,9).

Perinatal infection is an additional, potentially modifiable, risk factor for encephalopathy that has been linked to adverse outcomes. Among preterm neonates, chorioamnionitis and neonatal sepsis are associated with brain injury (and specifically white matter injury) and cerebral palsy (2,10–15). However, the role of perinatal infection among term neonates, especially those with a history of encephalopathy, is not well understood. Past studies suggest that chorioamnionitis is not an added risk factor for brain injury, whereas others studies suggest that neonatal sepsis may lead to impaired oxidative metabolism and abnormal neurodevelopmental outcomes in childhood (16,17). Definitive conclusions, however, are limited by the small sample sizes of these studies and/or lack of long-term outcomes.

In this study, we examined the hypothesis that, among term newborns with encephalopathy, maternal chorioamnionitis and/or signs of neonatal sepsis are associated with a higher risk of neonatal brain injury and worse long-term neurodevelopmental outcome.

RESULTS

Of the 295 patients enrolled into the cohort during the study period, 37 were excluded because of insufficient documentation to assess either maternal or neonatal infection (35 subjects), or MR images that were motion degraded (2 subjects). The clinical characteristics of the 258 subjects included in this analysis are presented in **Table 1**.

Forty-two (16%) of neonates had a maternal history of chorioamnionitis (28 with clinical chorioamnionitis, 20 with histological chorioamnionitis, 6 with both clinical and histological), whereas 29 (11%) had proven or suspected sepsis (4 with confirmed bloodstream infection and 25 with suspected sepsis). Six subjects (2%) had both maternal chorioamnionitis and signs of neonatal sepsis. Organisms identified from blood cultures included the following: *Escherichia coli*, 2 subjects; and Group B *streptococci* or unspeciated Gram-positive rods, 1 subject each. None of the 55 neonates with cerebrospinal fluid analysis had meningitis. Neonates with maternal chorioamnionitis had less severe markers of perinatal asphyxia; specifically, they had

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Table 1. Patient characteristics of 258 subjects with neonatal encephalopathy

	Chorioamnionitis ($N = 42$)[a]	Signs of neonatal sepsis ($N = 29$)[a]	No infection ($N = 193$)	P value
Male sex	26 (62%)	14 (48%)	106 (55%)	0.4
Gestational age, wk	40.2 ± 1.3	39.7 ± 2.0	39.5 ± 1.7	0.09
Birth weight, g	3,307 ± 522	3,197 ± 666	3,386 ± 596	0.4
Prolonged rupture of membranes >18 h	18 (43%)	7 (24%)	27 (14%)	0.005
Emergent cesarean section	11 (31%)	16 (55%)	79 (41%)	0.1
1-min Apgar score	2 (0–7)	2 (0–6)	2 (0–8)	0.6
5-min Apgar score	4 (0–9)	4 (0–9)	4 (0–9)	0.2
pH	7.12 ± 0.17	7.02 ± 0.16	7.01 ± 0.19	0.006
Base excess	−8.3 ± 4.9	−14.0 ± 6.5	−13.3 ± 7.0	0.0008
Encephalopathy score (19)	4 (1–6)	6 (1–6)	4 (0–6)	0.002
Neonatal EEG seizures	13 (30%)	13 (45%)	73 (38%)	0.5
Hypothermia therapy	18 (43%)	8 (28%)	66 (34%)	0.5
Deceased	2 (5%)	4 (14%)	13 (7%)	0.4

Data are presented as *n* (%), mean ± SD, or median (range).
EEG, electroencephalogram.
[a]Six subjects had both chorioamnionitis and signs of neonatal sepsis.

higher pH and higher base excess from the cord gas or initial blood draw, as well as a lower maximal encephalopathy score.

Brain Injury

Pattern of injury. Brain injury was present in 61% of subjects. The watershed predominant pattern of injury was the most common pattern, seen in 98 (38%) newborns, whereas 59 (23%) had the basal ganglia/thalamus predominant pattern; the remainder had normal brain imaging.

Infection status was associated with pattern of brain injury (**Figures 1** and **2**). Whether examining data by the three- or the four-category classification system, children of mothers with chorioamnionitis were more likely to have normal imaging than those without maternal chorioamnionitis. And the 29 infants with signs of neonatal sepsis were more likely to have injury in the watershed pattern than those without signs of neonatal sepsis. However, among the four children with confirmed bloodstream infection, two had the basal ganglia/thalamus pattern (group B *streptococci* and Gram-positive rods), one had the watershed predominant pattern of injury (*E. coli*), and 1 had a normal MRI (*E. coli*).

Severity of injury. Moderate–severe brain injury was present in 45% of subjects. Whereas neonates with maternal chorioamnionitis were less likely to have moderate–severe brain injury as compared with those without maternal chorioamnionitis (odds ratio (OR): 0.5; 95% confidence interval (CI): 0.1–0.7; $P = 0.003$; **Table 2**), neonates with signs of sepsis did not have altered risk of moderate–severe brain injury as compared with those without (OR: 1.3; 95% CI: 0.8–4.0; $P = 0.1$). Three of the four (75%) neonates with confirmed bloodstream infection had moderate–severe brain injury.

The decreased risk of severe brain injury on MRI in neonates with maternal chorioamnionitis remained significant after adjusting for maximal encephalopathy score and first pH (**Table 2**).

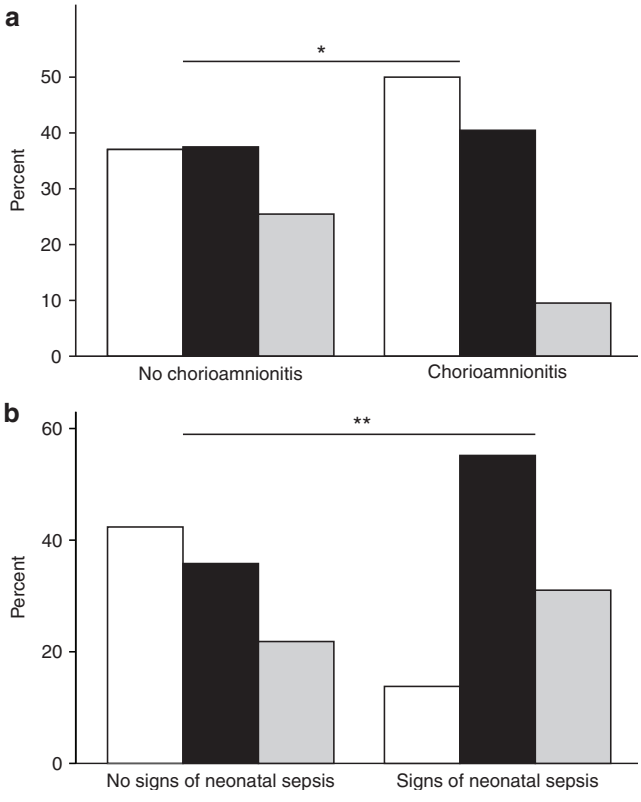

Figure 1. Association between infection and categorical pattern of brain injury among 258 neonates with encephalopathy with and without maternal chorioamnionitis (**a**) and signs of neonatal sepsis (**b**; χ^2). White indicates normal magnetic resonance imaging; black, watershed predominant pattern of injury; and gray, basal ganglia/thalamus injury. *$P = 0.053$; **$P = 0.007$.

Neurodevelopmental Outcome

Sixteen newborns died before the 30-mo evaluation (6%). Neither maternal chorioamnionitis nor signs of neonatal sepsis

in the neonate were associated with a higher risk of death (5% with maternal chorioamnionitis died vs. 6% without, $P = 1.0$; 10% with signs of neonatal sepsis died vs. 6% without, $P = 0.4$).

At the time of analysis, 194 subjects were eligible for 30-mo evaluation; 126 had a motor evaluation and 117 had a cognitive evaluation using either Bayley Scales of Infant Development, second edition (BSID II, 75 subjects) or Bayley Scales of Infant Development, third edition (Bayley III, 42 subjects) at a median age of 31 mo (interquartile range: 30–32 mo). Both cognitive and motor testing were completed in 115 subjects. There were no significant differences in sex, delivery route, birth weight, gestational age at birth, Apgar scores, encephalopathy score, neonatal seizures on electroencephalogram, or presence of maternal chorioamnionitis or signs of neonatal sepsis between the children with and without follow-up and between those tested with BSID II and Bayley III.

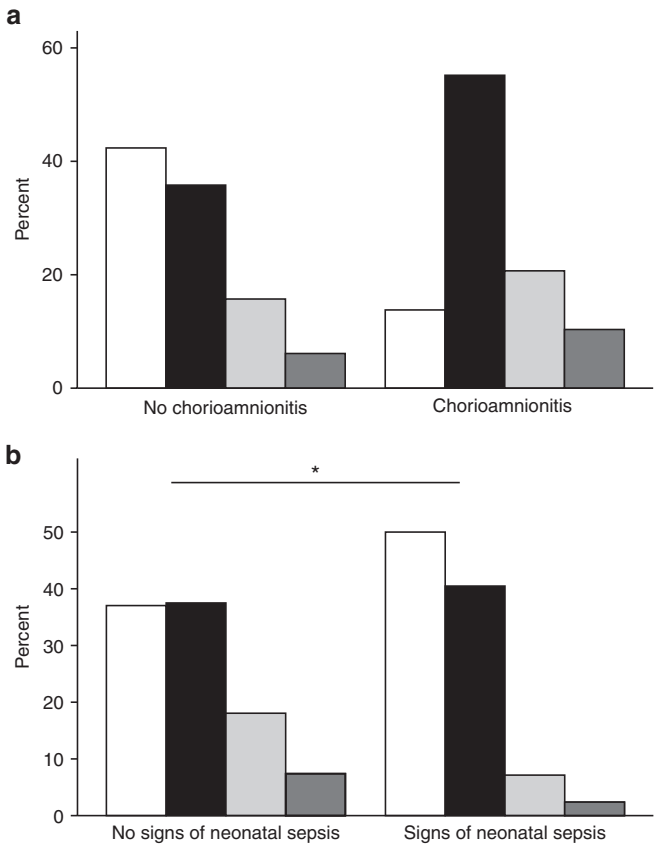

Figure 2. Association between infection and categorical pattern of brain injury among 258 neonates with encephalopathy with and maternal chorioamnionitis (**a**) and signs of neonatal sepsis (**b**; χ^2). White indicates normal magnetic resonance imaging; black, watershed predominant pattern of injury; gray, basal ganglia/thalamus injury; and dark grey, total injury (i.e., maximal basal ganglia/thalamus and watershed scores). *$P = 0.03$.

Motor outcome. The median neuromotor score was 0 (range: 0–5), and 26% had a neuromotor score ≥2. There was a trend toward lower (more normal) neuromotor score for children with maternal chorioamnionitis when compared with those without ($P = 0.1$). The odds of neuromotor score ≥2 among those neonates exposed to maternal chorioamnionitis was lower as compared with those without (OR: 0.3; 95% CI: 0.1–1.3; $P = 0.1$). In contrast, the median neuromotor score was higher for children with signs of neonatal sepsis (median neuromotor score: 2; range: 0–5), as compared with those without (median neuromotor score: 0; range: 0–5; $P = 0.02$). The odds of neuromotor score ≥2 in children with signs of neonatal sepsis were 4.6 (95% CI: 1.5–14.6; $P = 0.009$; **Table 3**).

After adjusting for maximal encephalopathy score and pH, associations between maternal chorioamnionitis or neonatal signs of neonatal sepsis and risk of neuromotor score ≥2 were similar, but no longer significant (chorioamnionitis OR: 0.5; 95% CI: 0.1–1.8; $P = 0.2$ and signs of neonatal sepsis OR: 3.4; 95% CI: 0.8–13.9; $P = 0.07$).

Cognitive outcome. Seventy-five children were tested using the BSID II with a median (range) BSID II mental development index of 86 (range, 50–121). After 2008, cognitive outcome was assessed with Bayley III in 42 children.

Median cognitive composite score was 100 (range: 65–145). Considering both scores, 21 (18%) of the assessed children had an abnormal cognitive outcome (23% had a mental development index <70 and 10% had a Bayley III cognitive score <85).

Maternal chorioamnionitis was associated with a lower risk of abnormal cognitive testing (none of those with exposure to maternal chorioamnionitis vs. 21% of those without had an abnormal score, $P = 0.03$; considering BSID II only, none of those with vs. 27% of those without had an abnormal score, $P = 0.06$). Signs of neonatal sepsis were associated with a higher risk of abnormal cognitive score, though the difference was not significant (33% of those with signs of neonatal sepsis vs. 16%

Table 2. Moderate or severe brain injury as seen on magnetic resonance imaging among 258 subjects with neonatal encephalopathy

	N	Moderate–severe injury, *n* (%)	OR (95% CI)			
			Unadjusted	Unadjusted *P* value	Adjusted[a]	Adjusted *P* value[a]
Chorioamnionitis						
Yes	42	10 (24)	0.3 (0.1–0.7)	0.003	0.3 (0.1–0.7)	0.004
No	216	107 (50)	Ref		Ref	
Signs of neonatal sepsis						
Yes	29	17 (58)	1.8 (0.8–4.0)	0.1	1.4 (0.5–3.5)	0.5
No	229	100 (44)	Ref		Ref	

CI, confidence interval; OR, odds ratio.
[a]Adjusted for maximal encephalopathy score and first pH.

Table 3. Chorioamnionitis, signs of neonatal sepsis, and risk of NMS ≥2 and BSID MDI <70 or cognitive subscore <85 among children with neonatal encephalopathy

			OR (95% CI)			
	N	NMS ≥2, *n* (%)	Unadjusted	Unadjusted *P* value	Adjusted[a]	Adjusted *P* value[a]
Chorioamnionitis						
Yes	19	2 (10)	0.3 (0.1–1.3)	0.1	0.5 (0.2–1.8)	0.3
No	107	31 (29)	Ref		Ref	
Signs of neonatal sepsis						
Yes	14	8 (57)	4.6 (1.5–14.6)	0.009	2.9 (0.9–9.3)	0.07
No	112	25 (22)	Ref			
	N	BSID II MDI <70 or Bayley III cognitive subscore <85, *n* (%)	Unadjusted	Unadjusted *P* value	Adjusted[a]	Adjusted *P* value[a]
Chorioamnionitis						
Yes	18	0	—	0.03	—	
No	99	21 (21)				
Signs of neonatal sepsis						
Yes	12	4 (33)	1.8 (0.8–4.0)	0.1	4.8 (0.5–41.9)	0.1
No	105	17 (17)	Ref			

BSID II, Bayley Scales of Infant Development, second edition; CI, confidence interval; MDI, mental development index; NMS, neuromotor score; OR, odds ratio.
[a]Adjusted for maximal encephalopathy score and first pH.

of those without, OR: 1.8; 95% CI: 0.8–4.0; $P = 0.1$). Among those children tested with BSID II only, there was no difference (27% of those with vs. 22% of those without, OR: 1.2; 95% CI: 0.4–3.6; $P = 0.7$).

DISCUSSION

In this cohort of term neonatal encephalopathy, children who were exposed to maternal chorioamnionitis had a lower risk of brain injury and adverse outcomes as compared with those without such exposure, whereas children with signs of neonatal sepsis had a higher risk of brain injury and adverse outcomes when compared with those without sepsis. These findings comport with prior animal and human studies that show a variable response of the developing brain to inflammation depending on the timing of exposure and developmental age of the subject (18,19).

There are several possible explanations for the apparent "protective" effect of chorioamnionitis in this cohort. First, it is possible that chorioamnionitis is a less harmful cause of low 5-min Apgar score and/or cord blood acidosis (which were cohort inclusion criteria) than hypoxia–ischemia, and thus exposed neonates are relatively less affected than other subjects in the cohort. This explanation is supported by the fact that subjects with a maternal history of chorioamnionitis had less severe markers of perinatal asphyxia, though this difference may also come from a wide range of other causes, including obstetric practice differences in response to an infected mother. An alternative explanation for the better outcomes among neonates exposed to chorioamnionitis is that the prenatal timing may have had a preconditioning effect that protected the child against injury from hypoxia–ischemia (18). Past studies provide inconclusive evidence about the relationship between chorioamnionitis and outcome. Chorioamnionitis has been linked to white matter injury and cerebral palsy in preclinical and human studies, with data coming from both individual studies and meta-analyses, and results being strongest among those children born preterm (20–26). The exact pathophysiology, however, remains inconclusive. Chau *et al.* (27) looked carefully at this question by examining a cohort of preterm neonates and found that histopathological chorioamnionitis was *not* associated with an increased risk of white matter injury (the predominant injury in preterm neonates), nor did it significantly affect measures of brain metabolic and microstructural development, whereas neonatal sepsis and hypotension were associated with these measures, making the neonatal illness that may follow maternal infection a more likely direct cause of adverse outcome. The lack of direct association between chorioamnionitis and adverse outcome has also been substantiated among term neonates: an investigation that accounted for severity of neonatal illness (hypotension, need for intubation, neonatal seizures, and encephalopathy) failed to demonstrate a significant relationship between maternal infection and adverse outcome (16). More recently, Harteman *et al.* (28) examined the relationship between placental pathology and brain imaging in a cohort of 95 neonates with encephalopathy. The authors found high rates of placental abnormalities among neonates with encephalopathy. As in our study, among subjects with exposure to chorioamnionitis (and especially high-grade chorioamnionitis), imaging was more likely to be normal (45% as compared with 27% of those who were not exposed to chorioamnionitis). The authors also found that the watershed predominant pattern was the most common injury. Harteman *et al.* (28) report more subjects with basal ganglia injury than we found in our cohort; however, their MR scoring system differs from ours, making exact comparisons difficult.

Animal data from Eklind *et al.* (18) suggest an explanation for a protective effect of chorioamnionitis leading to an

inflammatory environment for the fetus. This group showed that lipopolysaccharide enhanced hypoxic–ischemic injury when administered either 72 h before or 6 h after the insult, but reduced brain injury when administered 24 h before the hypoxic–ischemic injury. The investigators concluded that lipopolysaccharide augmented vulnerability with either acute or chronic administration, but that intermediate interval administration had a protective effect (18). The early sensitizing effect of lipopolysaccharide may be explained by an inflammatory and apoptotic response that is marked by upregulation of chemokines and cytokines, as well as upregulation of proapoptotic genes (18). However, lipopolysaccharide and other inflammatory mediators have also been shown to have a preconditioning effect similar to that of hypoxia–ischemia. The protective effect may be due to the induction of hypoxia-inducible factor and nitric oxide, as well as inhibition of caspases and induction of the antiapoptotic system. These factors are important for preconditioning in the setting of hypoxia–ischemia (reviewed in ref. 29).

The association between neonatal sepsis and adverse outcome is in keeping with that reported in the animal studies, which demonstrate that exposure to inflammation after the insult potentiates hypoxic–ischemic injury (18). The finding that the watershed pattern of injury was more common in those with neonatal inflammation is similar to what is seen in preterm neonates who have higher rates of white matter injury following sepsis and necrotizing enterocolitis (13,27,30,31). In the preterm population, this pattern of injury has been attributed to the selective vulnerability of oligodendrocyte precursor cells and also to blood pressure instability and perturbed cerebral autoregulation, which lead to shifts in cerebral perfusion and oxygenation (32). Blood pressure and cerebral perfusion monitoring data were not available for this cohort, so we cannot exclude that the association between signs of neonatal sepsis and outcome in this cohort is due to cardiovascular instability and cerebral hypoperfusion.

We acknowledge several limitations of this study. First, it is difficult to precisely measure effects of chorioamnionitis and neonatal sepsis because both conditions exhibit wide variability in presentation and severity. Differences in the quality and detail of the clinical reports, especially from children born in the beginning of the cohort, made it difficult to assess for the presence of clinical maternal infection. Only 37 patients had placental pathological examination, and we were unable to grade the severity of histological chorioamnionitis from the reports. The rate of chorioamnionitis in a similar cohort was higher (46%) (28), suggesting that we may have failed to capture the full burden of maternal infection, a misclassification that would bias us to the null hypothesis, making it more difficult to find associations within our data. Second, despite the large size of the total cohort, we had small numbers of the predictors and outcomes of interest, which may explain why some associations were not significant. The rate of sepsis in our cohort (11%) was very similar to the 5–14% rate seen in the hypothermia trials (33). Third, part of the cohort was lost to follow-up before 30 mo. Although the neonatal features of those children with and without follow-up were similar, we cannot exclude bias. Fourth, as did many other centers, we switched from the BSID II to the Bayley III midway through the cohort. When examining the effect of infection on cognitive outcomes, we chose the mental development index of the BSID II with cutoff of 70 and the Bayley III with cutoff of 85 for a dichotomous outcome measure to account for differences in the scales (34–36). The impact of the change in test is not known: when examining the subgroup of children tested with BSID II, we found no difference in results among those neonates exposed to chorioamnionitis; however, there was no estimated increase in adverse outcome among children with signs of neonatal sepsis. Finally, we also initiated therapeutic hypothermia midway through the cohort. The effect of hypothermia was not significant in this cohort; however, the effect of hypothermia on inflammation in the setting of neonatal encephalopathy is uncertain and merits further study.

Conclusions

These results suggest that neonatal sepsis potentiates brain injury in term neonatal encephalopathy, whereas chorioamnionitis was not associated with increased injury.

Basic and clinical research to elucidate the underlying pathophysiological mechanisms is necessary to better determine the influence of timing of infection in relation to perinatal insult.

METHODS

Subjects

Neonates were enrolled in an ongoing prospective cohort study of the use of MRI to predict outcome following risk of hypoxic–ischemic brain injury and encephalopathy from the Intensive Care Nursery of the University of California, San Francisco. Inclusion criteria for the cohort are gestational age ≥36 wk and any one of the following criteria: (i) first blood gas or umbilical cord artery pH <7.1, (ii) first blood gas or umbilical cord artery base deficit >10, and/or (iii) a 5-min Apgar score ≤5. These broad inclusion criteria were chosen to encompass newborns with a wide range of injury and neurodevelopmental outcome and have been used in previous publications by our group (37). Neonates with congenital malformation, inborn error of metabolism, or congenital infection that was suspected or diagnosed based on clinical, laboratory, or radiographic data were excluded. The University of California, San Francisco Committee on Human Research approved the research protocol, and parental informed consent was obtained for each subject.

From December 1993 to September 2011, 295 neonates were enrolled and imaged in the newborn period according to protocol. Trained neonatal research nurses prospectively collected prenatal, perinatal, and postnatal variables from maternal and neonatal hospital records. A pediatric neurologist determined encephalopathy scores (38). Therapeutic hypothermia using 72 h of whole-body cooling was initiated at our institution in November 2007 (39). Patients with seizures were managed at the discretion of the treating physician, typically with phenobarbital as the first-line agent.

For this study, the obstetric charts, neonatal charts, and microbiology reports were reviewed for signs of maternal and postnatal infection. Clinical chorioamnionitis was defined as maternal temperature >37.8 °C and uterine tenderness, or as maternal fever or uterine tenderness and one of the following: maternal tachycardia (>120 beats per minute, fetal tachycardia (>160 beats per minute), purulent or foul-smelling amniotic fluid or vaginal discharge, or maternal leukocytosis (total blood leukocyte count >15,000 cells/mm^3) within 72 h of delivery (40). Presence of histological chorioamnionitis was determined by review of the clinical histopathological reports when available (N = 37). The treating physician managed chorioamnionitis

according to local guidelines. Subjects with clinical and histological evidence of infection were combined for analysis.

Infants were considered to have "signs of neonatal sepsis" if there was a documented bloodstream infection (i.e., blood cultures positive for pathogenic species other than *Staphylococcus epidermidis*) (41) or if they met the following clinical criteria for suspected sepsis: (i) a low white blood cell count (≤5,000 cells/mm^3), (ii) a low absolute neutrophil count (<2,000 cells/mm^3), or (iii) a high immature/total ratio (≥0.45) and a neonatal temperature >38.0 °C (42,43) within the first 7 d of life.

Magnetic Resonance Imaging

MRI was performed in all newborns at a median of 5 d of life (interquartile range: 4–7 d). A specialized neonatal circularly polarized head coil was used on a 1.5-T Signa EchoSpeed system (GE Medical Systems, Fairfield, CT). Pentobarbital was used as sedation, if necessary. Imaging sequences were optimized for the neonatal brain and included the following: (i) sagittally acquired volumetric fast inversion recovery-prepped spoiled gradient echo images using 1-mm partition size, 256 × 256 acquisition matrix, 1 number of excitations, and 18-cm field of view; (ii) T2-weighted axial dual echo, spin echo with repetition time/echo time of 3,000/60–120 ms, 4-mm thickness, 1 excitation, and 192 × 256 acquisition matrix; and (iii) diffusion-weighted imaging for subjects enrolled from 1998 onward, SE echo planar imaging diffusion sequence with repetition time/echo time of 7,000/99 ms, field of view 180 mm, 3-mm thickness (no skip), 128 × 128 acquisition matrix, b value of 700 s/m^2 during acquisition in three directions from 1998 to 2003, six directions from 2003 to 2008, or 30 directions after 2008.

A pediatric neuroradiologist who was blinded to the neonatal course scored T1, T2, and diffusion-weighted images prospectively. Injury to the basal ganglia and thalamus (basal ganglia/thalamus) and the watershed areas was scored independently using a classification system that is predictive of neurodevelopmental outcome after neonatal encephalopathy (37). Pattern of injury was defined as "basal ganglia predominant" (basal ganglia/thalamus scores greater than or equal to watershed scores, or maximum basal ganglia/thalamus and watershed scores), "watershed predominant" (watershed scores greater than basal ganglia/thalamus scores), or "normal" (basal ganglia/thalamus and watershed scores normal) (6). Injury was considered "moderate–severe" if the basal ganglia/thalamus score was ≥2 or watershed score was ≥3 (44). "Total injury" was considered present if maximal basal ganglia/thalamus *and* watershed scores were present.

Neurodevelopmental Outcome

A developmental psychologist who was blinded to the neonatal course assessed cognitive outcome at a goal age of 30 mo. BSID II was administered before June 2008, after which the Bayley III was administered. For purposes of analysis, a BSID II mental development index <70 or Bayley III cognitive subscore <85 were considered abnormal (34–36). Neuromotor function was evaluated using the neuromotor score, which is based on tone, reflexes, and power and where 0 is normal and 5 is spastic quadriparesis (45). Neuromotor score ≥2 indicates an abnormal neurological examination. BSID II psychomotor development index scores were not available.

Analysis

Statistical analysis was performed using Stata 11 (StataCorp LP, College Station, TX). Neonates with or without either maternal or infant infection were independently examined in association with clinical and outcome variables using χ^2 and Fisher's exact test for categorical variables, Kruskal–Wallis equality-of-populations rank test for nonparametric continuous variables, and ANOVA for normally distributed continuous variables. There was no interaction between maternal chorioamnionitis and signs of neonatal sepsis, and as such, the two predictors were analyzed separately as affected group compared with unaffected group. Logistic regression was used to examine the association between the infection and presence of severe brain injury, neuromotor score ≥2, or abnormal cognitive outcome. To build a multivariable model, we used backward stepwise regression starting with all variables associated with either of the predictors, and at least one outcome at $P < 0.2$, as well as first pH as a face value variable.

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