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Prediction of Neuromotor Outcome in Perinatal Asphyxia: Evaluation of MR Scoring Systems

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PURPOSE: **We developed a scoring system for the assessment of perinatal asphyxia as depicted on MR images.**

METHODS: **Four scoring systems were derived to evaluate MR images obtained in asphyxiated neonates: the basal ganglia (BG) score, the watershed (W) score, the combined basal ganglia/watershed (BG/W) score, and the sum of the BG and W scores, the summation (S) score. In addition, three MR sequences, T1-weighted, first-echo T2-weighted, and second-echo T2-weighted, were assessed for each patient for each scoring system. Neuromotor examinations were performed at ages 3 and 12 months, and cognitive development was tested at age 12 months. Statistical analysis was then performed to test the relationship between the MR scores and the outcome scores.**

RESULTS: **The BG/W score, obtained with the first-echo T2-weighted sequence, was the most useful overall score for predicting neuromotor outcome at 3 and 12 months and cognitive outcome at 12 months. T1-weighted and first-echo T2-weighted sequences showed a stronger association with outcome in patients imaged during the first postnatal week, whereas second-echo T2-weighted sequences showed a stronger association with outcome in patients imaged during the second postnatal week.**

CONCLUSION: **It appears that, with the use of the BG/W score, MR imaging discriminates accurately between patients with good and poor neuromotor and cognitive outcome at 3 and 12 months. In terms of our scoring systems, the first-echo T2-weighted sequence appears to discriminate best between patients with good and poor 3- and 12-month outcomes. Proper use of the imaging sequences and scoring systems described in this article can increase the knowledge base upon which treatment decisions are made in asphyxiated neonates.**

Magnetic resonance (MR) imaging has been found to be a useful tool for the early evaluation of brain injury in asphyxiated neonates (1–5). Most studies performed to date have used standard T1- and T2-weighted sequences to examine these patients. Some investigators (6) have developed scoring systems to evaluate the imaging findings and to compare them with clinical outcome. However, none has devised and compared scoring systems using different imaging sequences (T1-weighted, T2-weighted, proton density–weighted) to evaluate asphyxia in neonates during the first days after birth. In this study, we introduce and appraise several scoring systems, using T1-weighted sequences, the first and second echoes of T2-weighted sequences, and contrast-enhanced sequences obtained in the early postnatal period, in a prospective cohort of asphyxiated neonates. We then compare these scores with neuromotor outcome at ages 3 months and 12 months.

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Methods

Patient Data

As part of an ongoing study of the utility of neonatal brain MR imaging in the assessment of brain damage in asphyxiated term neonates, 2241 consecutive term neonates born at or transferred to the Intensive Care Nursery at our institution were screened using the following entry criteria: umbilical artery pH less than 7.1; umbilical artery base deficit greater than 10; and 5-minute Apgar score less than or equal to 5. Patients fulfilling any one of these criteria were considered eligible for this study. Patients with suspected or confirmed congenital malformations or congenital infections and patients born be-

TABLE 1: Patient population

Total number of patients:	53
Sex distribution:	33 boys, 20 girls
Mean birth weight:	3319 g (SD, 730 g)
Median 1-minute Apgar score:	3 (range, 0 to 6)
Median 5-minute Apgar score:	5 (range, 0 to 9)
Median 10-minute Apgar score:	7 (range, 1 to 10)
Mean umbilical artery pH:	7.0 (range, 6.77 to 7.32; SD, 0.14)
Mean umbilical artery base excess:	12.5 (range, −27 to −4; SD, 6.3)

fore 36 weeks' gestational age were excluded from the study. The protocol was approved by the Committee on Human Research at our institution. Participation in the study was voluntary; the infants were studied only after informed consent was obtained from their parents.

Of the 2241 patients screened, 259 met the inclusion criteria. Of these, 47 were excluded on the basis of suspected or confirmed malformation or infection; parents declined enrollment in 142 cases, and refused the MR study after enrollment in 10 cases. To date, 65 patients have been enrolled and studied by MR imaging. Of these, two died before the 3-month examination, 51 completed the 3-month neuromotor examination, two died between the 3-month and 12-month neurodevelopmental examination, 32 completed the 12-month neurodevelopmental examination, and one was lost to follow-up. The 53 patients with known 3-month outcome (including the 36 with known 12-month outcome) constitute the group whose findings are reported in this article (Table 1). The group included 18 Hispanic patients (34%), 15 white patients (28%), 11 Asian patients (21%), eight black patients (15%), and one Native American patient (2%). Patients' ages at the time of the MR examination ranged from 1 to 17 days, with a mean age of 7 days. An attempt was made to image the patients as soon as they were stable enough to be safely transported to the MR scanner; thus, most patients were imaged during the first week of life. However, other factors, such as MR schedule, availability of a physician to transport and monitor the infant, and delays in obtaining parental consent sometimes caused the MR examination to be postponed.

MR Data

The MR examination, performed at 1.5 T, consisted of noncontrast 4-mm (1-mm gap) axial spin-echo 500/11/2 (repetition time/echo time/excitations) images and 4-mm (2-mm gap) axial spin-echo 3000/60,120/1 images through the entire brain. Axial 4-mm (1-mm gap) spin-echo 500/11/2 images were then obtained after intravenous infusion of 0.1 mmol/kg of gadopentetate dimeglumine. After obtaining the images, we evaluated the studies using four scoring systems (Table 2). These scoring systems were based on reports that imaging patterns in asphyxiated neonates fall into two basic categories, one in which the primary damage is to the deep gray matter nuclei and another in which the damage is primarily to the intravascular boundary zones (1, 6–9). Scoring was performed by a neuroradiologist who was blinded to all clinical parameters and outcomes; scores were sent to a data manager who performed the statistical analyses. The first set of scores, the basal ganglia (BG) score, was based on reports that neonates who have suffered cardiocirculatory arrest incur damage to the thalami, basal ganglia, and perirolandic cortex (1, 2, 6, 8). Because this score focused on the basal ganglia pattern of injury, isolated cortical infarctions (that is, focal embolic or thrombotic infarcts and watershed infarctions) were given a score of zero. Higher scores were given if injury was more extensive. For example, injury to the lentiform nucleus and thalamus is more extensive than injury to just the thalamus; therefore, the former was given a score of 2 and the latter a score of 1. Similarly, involvement of the perirolandic cortex, lentiform nucleus, and thalamus, more extensive still, was given a score of 3. A score of 4, "more extensive involvement," was assigned if the cortex was involved beyond the perirolandic region or if brain stem or cerebellar damage was detected. The second set of scores, the watershed score, was based on reports that neonates with hypotension and impaired autoregulation suffer damage to the white matter and cortex in the intervascular boundary zones, those regions between the territories perfused by the major cerebral arteries (1–3, 10). As with all the scoring systems, lower scores were given for less extensive damage and higher scores were given for more extensive damage. A score of 5, "more extensive cortical involvement," was assigned if cortical damage extended beyond the watershed areas. The third set of scores, the BG/W (for basal ganglia/watershed) score, was an attempt to combine the basal ganglia and watershed patterns of injury into a single score. Again, higher scores were given for more extensive damage. The fourth score, the summation score (S), was another attempt to combine the basal ganglia and watershed patterns into a single score; it was created by adding together the basal ganglia and watershed scores. A fifth score, the enhancement score (E), was determined by reviewing the postcontrast images. A T1-weighted image score, a first-echo T2-weighted image score, and a second-echo T2-weighted image score were assigned for

TABLE 2: Scoring systems

Score	Finding
Basal ganglia (BG)	
0 =	Normal or isolated focal cortical infarct
1 =	Abnormal signal in thalamus
2 =	Abnormal signal in thalamus and lentiform nucleus
3 =	Abnormal signal in thalamus, lentiform nucleus, and perirolandic cortex
4 =	More extensive involvement
Watershed (W)	
0 =	Normal
1 =	Single focal infarction
2 =	Abnormal signal in anterior or posterior watershed white matter
3 =	Abnormal signal in anterior or posterior watershed cortex and white matter
4 =	Abnormal signal in both anterior and posterior watershed zones
5 =	More extensive cortical involvement
Basal ganglia/watershed (BG/W)	
0 =	Normal
1 =	Abnormal signal in basal ganglia or thalamus
2 =	Abnormal signal in cortex
3 =	Abnormal signal in cortex and basal nuclei (basal ganglia or thalami)
4 =	Abnormal signal in entire cortex and basal nuclei
Summation (S)	
	Arithmetic sum of BG and W
Enhancement (E)	
0 =	No enhancement
1 =	Enhancement in white matter only
2 =	Enhancement in deep gray matter nuclei
3 =	Enhancement in cerebral cortex
4 =	Enhancement in cortex and deep gray matter or white matter

each of the noncontrast scoring systems. Thus, the MR study of each patient generated 12 scores from the noncontrast images: three basal ganglia scores (BG, T1-weighted; BG, first-echo T2-weighted; and BG, second-echo T2-weighted); three watershed scores (W, T1-weighted; W, first-echo T2-weighted; and W, second-echo T2-weighted); three basal ganglia/watershed scores (BG/W, T1-weighted; BG/W, first-echo T2-weighted; and BG/W, second-echo T2-weighted); and three summation scores (S, T1-weighted = BG, T1-weighted + W, T1-weighted; S, first-echo T2-weighted = BG, first-echo T2-weighted + W, first-echo T2-weighted; and S, second-echo T2-weighted = BG, second-echo T2-weighted + W, second-echo T2-weighted).

Each MR study was evaluated twice by the same observer. The evaluations were separated in time by more than a month. The first and second sets of scores were then compared and intraobserver variability was calculated. In those cases in which the scores differed on the two readings, the discrepancy was resolved by a third reading to give a final score. The final scores were then correlated with neuromotor outcome.

Developmental Examinations

At ages 3 months and 12 months, the subjects were examined by an experienced child neurologist, who was blinded to the results of the imaging studies and to the clinical course of the infant. The results of the neurologic examination were classified as *normal, abnormal,* or *unclear* at age 3 months. All patients with an unclear result who were subsequently examined at age 12 months were found to be normal on the second neuromotor examination. Thus, infants with an unclear evaluation at age 3 months were grouped with the normal infants for purposes of analysis. Patients who died before undergoing neuromotor examination were included in the study and classified as abnormal. At age 12 months, in addition to the standard neurologic examination, development was assessed by administering the Mental Developmental Index (MDI) of the Bayley Scales of Infant Development II (11).

Data Analysis

Statistical analysis was performed by using a commercial statistics program. Predictor variables were the 12 different MR imaging scores, analyzed as ordinal data. These scores were assessed for degree of association with neurologic outcome (normal or abnormal) at ages 3 and 12 months. Association between MR scores and outcome was analyzed using the Mann-Whitney U test. Association of MR scores with cognitive outcome (as measured with the MDI) was performed by using Kruskal Wallis analysis of variance (ANOVA) by ranks.

The κ statistic, which can also be interpreted as the intraclass correlation coefficient, was used to assess interscore agreement (12). This was calculated for each of the 10 assessments made from the MR images (BG, T1-weighted; BG, first-echo T2-weighted; BG, second-echo T2-weighted; W, T1-weighted; W, first-echo T2-weighted; W, second-echo T2-weighted; BG/W, T1-weighted; BG/W, first-echo T2-weighted; BG/W, second-echo T2-weighted) and enhancement score.

Analysis of Optimum Timing and Sequences of MR Images

A problem arose concerning the optimal imaging sequence for scoring the MR studies. We knew that T1-weighted images are sensitive to the T1 shortening in the basal ganglia and perirolandic cortex; however, it is also well known that T1-weighted images are not as sensitive to early cortical ischemia as are T2-weighted images. In addition, we noted that gray matter structures were sometimes isointense with white matter on the first echo of the T2-weighted images (Figs 1 and 2) in spite of a normal appearance on the second echo. These issues resulted in a decision to score each MR study such that a separate score was given for the T1-weighted sequence, the first echo of the T2-weighted sequence, and the second echo of the T2-weighted sequence in each scoring system. This generated 12 scores from the noncontrast studies of each patient, as described earlier.

The appearance of the injured brain changes considerably during the first 17 days after injury. Therefore, the usefulness of the different MR sequences might be different on different postnatal days. To test this hypothesis, we analyzed the MR scores after they were segregated according to the day of life on which they were obtained. Because a large number of patients were examined at age 3 months, we were able to categorize those patients into three groups: those imaged before day 4; those imaged before day 8; and those imaged on or after day 8. Because a smaller number of patients had 12-month neurodevelopmental examinations, analysis could be performed only if the patients were separated into two groups: those imaged before day 7 and those imaged on or after day 8.

Results

Consistency of Scoring

The κ values for each measured MR score ranged from 0.85 to 1.00 (Table 3). These values show high consistency of the scoring; that is, low intraobserver variability.

Association of MR Scores with Outcomes (Table 3)

Associations between MR score and the 3-month neuromotor outcome were calculated using the Mann-Whitney test. The following scores were significantly different between the normal and abnormal outcome groups: BG, first-echo T2-weighted images ($P = .0004$); BG/W, T1-weighted images ($P = .002$); BG/W, first-echo T2-weighted images ($P = .0007$); S, T1-weighted images ($P = .004$); and S, first-echo T2-weighted images ($P = .004$).

Associations between the MR score and 12-month neuromotor outcome (Mann-Whitney test) showed the following scores to be significantly different between the normal and abnormal outcome groups: BG, first-echo T2-weighted images ($P = .002$); BG/W, first-echo T2-weighted images ($P = .0001$); S, second-echo T2-weighted images ($P = .005$); and the enhancement score ($P = .005$).

Using the Kruskal Wallis ANOVA for comparing MDI and MR scores, we found the following significant associations: BG, first-echo T2-weighted images ($P = .007$); W, first-echo T2-weighted images ($P = .01$); and BG/W, first-echo T2-weighted images ($P = .01$).

Timing of MR Images (Table 4)

Three-Month Neuromotor Examination Correlations.—Of the examinations performed before the fourth postnatal day, only the first echo of the T2-weighted images (BG, first-echo T2-weighted; and BG/W, first-echo T2-weighted) was adequately sensitive to show correlation with the 3-month neuromotor examination. Both the T1-weighted images (BG, T1-weighted; BG/W, T1-weighted; and S, T1-weighted) and the first echo of the T2-weighted images (BG, first-echo T2-weighted; BG/W, first-echo T2-weight-

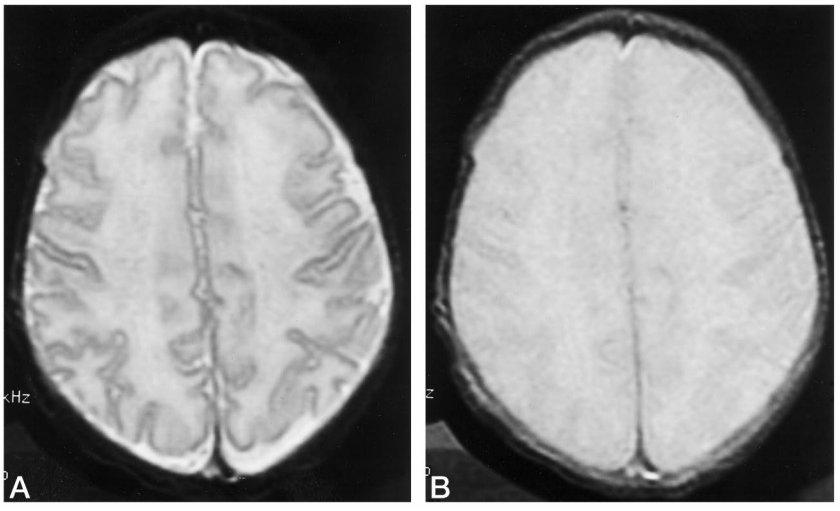

FIG 1. MR imaging at age 2 days shows value of first echo in an asphyxiated neonate, who was found to have both motor and cognitive deficits at age 12 months.

A, Axial spin-echo (3000/120) image shows apparently normal cortex and white matter. The apparent loss of cortex posteriorly is the result of a chemical-shift artifact.

B, Axial spin-echo (3000/60) image shows cortical edema, resulting in marked loss of normal cortical/white matter contrast.

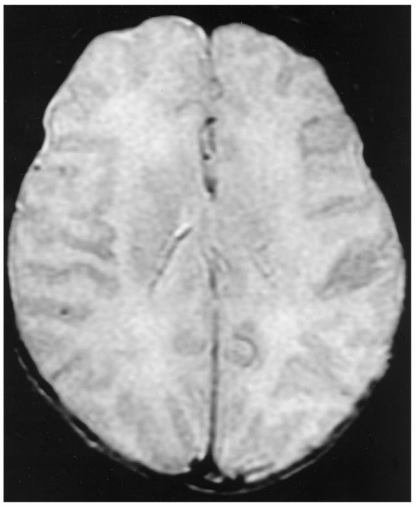

FIG 2. Axial spin-echo (300/60) image in a healthy 2-day-old term neonate. Note how much more contrast is present between cerebral cortex and white matter than in Figure 1B.

ed; and S, first-echo T2-weighted) from MR examinations performed before the eighth postnatal day correlated with outcome. Among the images obtained on or after the eighth postnatal day, the first and second echoes of the T2-weighted images (BG, first-echo T2-weighted; W, second-echo T2-weighted; BG/W, first-echo T2-weighted; BG/W, second-echo T2-weighted; S, second-echo T2-weighted) and the postcontrast studies correlated with outcome.

Twelve-Month Neuromotor Examination Correlations.—Of the studies performed before the seventh postnatal day, the T1-weighted and first-echo T2-weighted sequences (BG, T1-weighted; BG, first-echo T2-weighted; and BG/W, T1-weighted) correlated best with outcome. Of the studies performed after 7 postnatal days, the first and second echo of the T2-weighted studies (BG, first-echo T2-weighted; BG, second-echo T2-weighted; BG/W, first-echo T2-weighted; BG/W, second-echo T2-weighted; S, second-echo T2-weighted) and the enhancement score correlated best with neuromotor outcome.

Twelve-Month Mental Development Correlations.—Of the studies performed before 7 postnatal days, the T1-weighted sequences (BG, T1-weighted; BG/W, T1-weighted; and S, T1-weighted) and the first echo of the T2-weighted sequences (W, first-echo T2-weighted) showed significant correlation with the MDI of the Bayley Scales. Of the studies performed after 7 postnatal days, the first and second echoes of the T2-weighted studies (BG, first-echo T2-weighted; W, first-echo T2-weighted; W, second-echo T2-weighted; S, second-echo T2-weighted) again showed the best correlations. The enhancement score also showed a significant correlation ($P = .02$) with the MDI score.

Discussion

As MR imaging is used more frequently in the assessment of asphyxia in neonates, the importance of having a systematic scoring system for determining the severity of brain injury becomes increasingly apparent. However, the MR patterns and signal intensity changes of brain injury in the asphyxiated neonate are complex; they vary with the type and acuity of injury at the time of the study. Edema results in some T2 prolongation within affected regions within 24 hours (1–3, 5, 13–16). By day 3, T1 shortening may develop, particularly in the basal ganglia and perirolandic cortex (1, 6, 14, 15). By day 6 or 7, T2 shortening may be present (1, 14, 15). The location of brain injury seems to vary with the severity of reduction of blood flow (1, 7, 8, 13, 17–19). Because of this complexity of patterns and signal changes, the form for an optimal scoring system was not obvious. Therefore, several scoring systems were devised with the intent of correlating them with neurodevelopmental outcome, the ultimate goal of our project. Initially, two scoring systems were formulated. One was based on the pattern seen in circulatory arrest, which was designated the basal ganglia (BG) score. The other was based on the watershed pattern and was labeled the watershed (W) score. Soon after starting, it became apparent that it would be useful to test a system that included aspects of both patterns. This was accomplished in two ways, resulting in two different combination scores: one score that included components of both patterns of injury (the BG/W score), and one that was a simple arithmetic sum of the BG and W scores (the S, or summation, score). For the BG/W score, it was not initially clear how to weigh the various components of the injury pattern; that is, whether basal ganglia injury should be given a score

TABLE 3: κ coefficients and *P* values for MR scores and neuromotor outcome

Measurement	κ	3-Month Neuromotor Score	12-Month Neuromotor Score	MDI of BSID
BG, T1-weighted	0.929	0.008	0.11	0.14
BG, first-echo T2-weighted	0.936	0.0004	0.002	0.007
BG, second-echo T2-weighted	1.000	0.39	0.13	0.03
W, T1-weighted	0.851	0.54	0.14	0.2
W, first-echo T2-weighted	0.846	0.24	0.01	0.01
W, second-echo T2-weighted	0.891	0.007	0.008	0.12
BG/W, T1-weighted	0.863	0.002	0.03	0.03
BG/W, first-echo T2-weighted	0.891	0.0007	0.0001	0.01
BG/W, second-echo T2-weighted	0.927	0.02	0.04	0.1
S, T1-weighted	. . .	0.004	0.04	0.06
S, first-echo T2-weighted	. . .	0.004	0.79	0.03
S, second-echo T2-weighted	. . .	0.006	0.006	0.5
Enhancement	1.000	0.09	0.005	0.14

Note.—κ refers to the κ statistic for that measurement; 3-month neuromotor score indicates *P* values for differences in median MR scores for 3-month neuromotor outcome; 12-month neuromotor score indicates *P* values for differences in median MR scores for 12-month neuromotor outcome; MDI of BSID refers to the differences of the Mental Development Index of the Bayley Scores of Infant Development among scores of different MR assessments.

TABLE 4: *P* values for differences in MR scores for 3- and 12-month outcome: differences by timing of MR examination

Measurement	3-Month Neuromotor Outcome			12-Month Neuromotor Outcome		12-Month MDI	
	MR < 4 d	MR < 8 d	MR ≥ 8 d	MR < 7 d	MR ≥ 7 d	MR < 7 d	MR ≥ 7 d
BG, T1-weighted	0.30	0.05	0.13	0.02	0.66	0.04	0.31
BG, first-echo T2-weighted	0.009	0.005	0.03	0.04	0.04	0.07	0.006
BG, second-echo T2-weighted	1.00	0.79	0.31	1.0	0.05	. . .	0.02
W, T1-weighted	1.00	0.79	0.37	0.65	0.02	0.62	0.001
W, first-echo T2-weighted	0.17	0.43	0.42	0.20	0.02	0.004	0.002
W, second-echo T2-weighted	0.09	0.37	0.003	0.58	0.004	0.78	0.005
BG/W, T1-weighted	0.21	0.03	0.07	0.04	0.22	0.06	0.02
BG/W, first-echo T2-weighted	0.009	0.02	0.02	0.07	0.001	0.18	0.004
BG/W, second-echo T2-weighted	0.30	0.60	0.006	0.52	0.005	0.12	0.006
S, T1-weighted	0.30	0.03	0.10	0.018	0.26	0.04	0.08
S, first-echo T2-weighted	0.009	0.02	0.13	0.58	0.48	0.12	0.47
S, second-echo T2-weighted	0.09	0.37	0.002	0.58	0.003	0.78	0.004
Enhancement	1.000	0.68	0.005	0.68	0.0005	0.20	0.02

Note.—MDI means mental development index of the Bayley Scales of Infant Development.

of 1 and watershed injury a score of 2 or vice versa. Some of our previous experience and that of others (1, 6), however, indicated that patients with T1 shortening in the basal ganglia may not always manifest neurologic or developmental abnormalities. Thus, we opted to give a score of 1 for the basal ganglia injury and 2 for the watershed injury.

From our analysis, it appears that the BG/W, first-echo T2-weighted score is clearly the single most useful score for predicting outcome at 3 months and 12 months, because it shows significant differences between patients who had normal and abnormal neuromotor examinations at 3 ($P = .0007$) and 12 ($P = .0001$) months and between those who have normal and abnormal cognitive outcome at 12 months ($P = .007$). That the BG/W score is more predictive than the BG or W score alone is not surprising in that the BG/W score best evaluates injury to the entirety of the brain. The reason the BG/W score correlates with outcome better than the S score is not as obvious. Nonetheless, the results make it clear that the BG/W score is better.

A number of other interesting results deserve discussion. The BG score appears to better correlate with outcome at age 3 months than does the W score, whereas, in general, the W score seems to correlate better with outcome at age 12 months. This finding might be explained by the fact that the basal ganglia are more metabolically active than the cerebral cortex in the first months of life (20). Indeed, other than the perirolandic and calcarine regions, cerebral cortical activity during the first few months is quite low compared with the basal ganglia; this relatively low activity may perhaps explain why poor correlation was found between watershed injury and neurodevelopmental abnormalities at age 3 months. Relative cortical activity is much higher by age 1 year, perhaps explaining the better correlation between watershed injury and 12-month outcome.

When we looked at associations of MR scores with

outcome after segregating patients according to age at the time of their MR examination (Table 4), we found that, in addition to the patterns discussed above, the spin-echo 3000/60 (first-echo T2-weighted) sequences showed greatest differences between outcome groups (and thus were presumably most sensitive to injury) in those patients scanned during the first 3 postnatal days. Both the T1-weighted studies and the first-echo T2-weighted studies showed good correlation with neurologic outcome on those images obtained during the first 7 postnatal days. The first-echo T2-weighted sequences and the second-echo T2-weighted sequences showed the best correlation with outcome in those patients imaged after 7 or 8 postnatal days. The greater correlation of the T1-weighted images, as compared with the second-echo T2-weighted images, during the first postnatal week is most easily explained by the fact that T1 shortening in the basal nuclei and perirolandic cortex is seen as early as 3 days after injury (1). Those regions that manifest T1 shortening often show no changes on the second-echo T2-weighted images until the sixth or seventh day, when T2 shortening can be detected (1, 13–15). The reason for the increased sensitivity of the first-echo T2-weighted images (Fig 1) as compared with the second-echo T2-weighted images, during the first postnatal week is more difficult to explain. Intuitively, one might expect the second-echo T2-weighted sequences to be more sensitive to injury, as the longer echo time allows more time for the many causes of T2 relaxation to take effect; as a result, those differences in the T2 relaxation rate of normal versus damaged cortex might be magnified. However, it is possible that the difference between the T2 relaxation times of normal and damaged cortex is greater at the time of the first echo (60 milliseconds) because the increased water in the damaged cortex is more apparent on a more proton density–weighted image. Use of a shorter first echo to produce a more truly proton density–weighted image may help to clarify this question.

Another interesting finding is the fact that correlation with outcome was generally better in those patients whose MR examinations were performed after the first week as compared with those performed during the first week. This result is most easily explained by two factors. The first is that the tissue changes in the damaged brain are more advanced and, therefore, more easily detected during the second week than during the first week. The second is that, during the early stages of our study, many of the most severely injured patients were imaged during the second week. As our neonatologists have become more confident of the safety of performing MR studies on sick neonates, we have imaged more sick patients during the first few postnatal days. However, because of the reluctance to perform early imaging on severely injured patients during the early phases of our study, the group imaged during the second week contained a high proportion of infants with severely abnormal imaging studies and severely abnormal outcomes. When the MR images are very obviously abnormal, the abnormality can be detected by any imaging sequence and is reflected in nearly every scoring system. This result might be used as an argument that the imaging study should be delayed until the second, or even third, week of life in order to achieve maximum sensitivity. However, although it is useful to be able to prognosticate outcome in asphyxiated neonates, a more important purpose of MR imaging in these patients is to identify those in whom pharmacologic (or other) intervention might be indicated when such intervention becomes available. Therefore, early identification of those infants at high risk for poor neurodevelopmental outcome is critical. This study indicates that early identification of asphyxiated neonates at high risk for neurodevelopmental abnormality can be obtained by the use of MR imaging using our BG/W scoring system and by analyzing the first echo of the T2-weighted sequence. We are presently including diffusion-weighted imaging in our protocol. It is possible that diffusion imaging, using the scoring systems described in this article, may prove even more useful than the first-echo T2-weighted sequence in the first few days after injury.

Conclusion

We have tested several systems for scoring MR images of asphyxiated neonates. It appears that our BG/W score is able to discriminate accurately between patients with good and poor neuromotor and cognitive outcome at 3 months and 12 months. During the first 3 postnatal days, the first echo of the T2-weighted sequence appears to be the most sensitive sequence. The T1-weighted sequence becomes more sensitive during the latter half of the first week of life and the second echo of the T2-weighted sequence becomes more sensitive during the second week of life. This preliminary study shows the feasibility of using these MR scoring systems to predict outcome in asphyxiated neonates. Proper use of these imaging sequences and scoring systems will help to increase the knowledge base upon which treatment decisions are made in this group of infants.

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