The Role of Early MR in the Evaluation of the Term Infant with Seizures

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PURPOSE: To define the role of MR in evaluating term neonates with seizures, the most common clinical manifestation of cerebral injury in neonates. **METHODS:** Fifteen term infants with seizures underwent MR imaging. The presence and pattern of MR findings were compared with clinical markers of perinatal distress, cause of cerebral injury, and short-term neurologic outcome. **RESULTS:** Seizures were caused by hypoxic-ischemic encephalopathy in three patients, bacterial meningitis in three, and prenatal cocaine exposure in one. Nine patients had no identifiable risk factors. By MR, five patients had focal ischemic injury of the cerebral hemispheres and/or basal ganglia and brain stem. Six patients had diffuse cerebral edema: of these, five had basal ganglia edema; one had brain stem edema. One patient had superior sagittal sinus thrombosis with venous infarcts. Three patients had normal MR studies. There was no correlation between markers of perinatal distress, risk factors for seizures, and presence or pattern of MR findings. There was some correlation between MR findings of diffuse cerebral injury and neurologic outcome, and between MR findings of basal ganglia and brain stem abnormalities and neurologic outcome; these findings correlated with spasticity and hemiplegia at 6 to 24 months follow-up. **CONCLUSION:** The presence or pattern of MR findings does not appear to correlate with clinical signs of perinatal distress or presumed causes of perinatal cerebral injury. Further investigation is needed to identify prospectively neonates with seizures who are at risk for significant neurologic morbidity.

Index terms: Seizures; Infants, newborn; Magnetic resonance, in infants and children

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Seizures are a frequent and nonspecific manifestation of cerebral injury in neonates (1). Magnetic resonance (MR) is more sensitive than computed tomography (CT) in detecting cerebral injury in adults (2). However, the normal high water content of the immature brain may limit the inherent sensitivity of MR in infants (3). We prospectively evaluated the MR findings in 15 term neonates presenting with seizures to define the role of MR in this clinical setting. The infants also underwent cranial ultrasound (US) as standard care in the intensive care unit. Although direct comparison between MR and US is not possible in all the patients, we identified the insensitivity of US to some ischemic lesions readily seen on MR.

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Materials and Methods

We prospectively studied 15 term neonates (estimated gestational age 39.5 ± 1.94 weeks) presenting with perinatal seizures over a 14-month period ending December 1992. Fourteen patients were admitted to the neonatal intensive care unit at our institution, and one patient was transported to our site for MR imaging from an outside neonatal intensive care unit. The patients underwent MR imaging as soon as clinical status permitted transport.

MR imaging was done on a 0.5-T superconducting unit. One patient required assisted ventilation because of lack of spontaneous respirations since birth. Patients requiring sedation received oral choral hydrate in a dose of 50 mg/kg. Patients were monitored using a peripheral oxygen saturation and pulse monitor. Routine sequences included sagittal T1-weighted spin-echo (500/20/2 [repetition time/echo time/excitations]), axial T1-weighted spin-echo or gradient-echo (30/13/1, 30° flip angle), and axial T2-weighted spin-echo (4500/35,120/1).

All patients underwent cranial US as standard care in the intensive care unit, one at an outside hospital. US was performed with a 7/5.0-mHz transducer through the anterior fontanelle. Imaging parameters were power −6 dB, gain −7 dB, and log compensation 57 dB. Initial cranial US was performed within 24 hours of seizure activity in 13 patients, at 4 days in one, and 7 days in one. Follow-up US was performed thereafter as indicated by clinical status (Table 1). Autopsy results were available in the one patient who died in the perinatal period. Clinical follow-up ranging from 6 to 24 months was available in 14 patients; five have had follow-up MR studies.

MR images were assessed according to the signal intensity of the basal ganglia, brain stem, and cortical ribbon, which are normally hypointense relative to the cerebral white matter on T2 images (3). The white matter of the cerebral hemispheres was subjectively assessed as normal if the sulci were not effaced, and the white matter, which is normally hyperintense in T2 images, was homogeneous and not higher in signal intensity than on T2 images from healthy neonates imaged at our site (Fig 1). White matter signal intensity was also assessed on the T1 images in comparison with healthy control subjects. MR studies were interpreted without knowledge of the US findings.

Cranial US images were assessed according to the echogenicity of the cerebral sulci, which are normally well defined, and the presence of focal or diffuse areas of increased echogenicity within the cerebral parenchyma, basal ganglia, and brain stem (4). US studies were interpreted without knowledge of the MR findings.

Statistical Analysis

The Fisher Exact Test was used to evaluate for association between clinical features at birth, pattern or presence of MR findings, and short-term clinical outcome.

TABLE 1: Temporal relationships between US and MR imaging

Patient	Age at US (Days)	Age at MR (Days)	Days between Most Recent US and MR
1	1, 4, 6	14	8
2	1, 3, 5	6	1
3	1–7, 15, 17	22	5
4	1, 7, 8	11	3
5	1, 3	4	1
6	8	10	2
7	7	9	2
8	3, 5, 9+, 19	10	1
9	1, 4, 5+, 11	13	2
10	1, 7	6	1
11	2, 4+, 7	12	5
12	2, 3, 4, 12	4, 12+	0
13	2	10	8
14	2+, 15	17	2
15	2, 3, 13	14	1

+ indicates most abnormal imaging study.

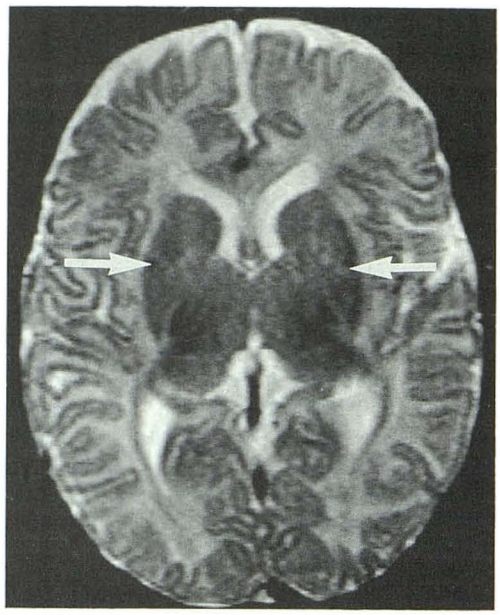


Fig. 1. Normal neonatal brain. Heavily T2-weighted axial image shows that unmyelinated cerebral white matter is hyperintense relative to the sharply defined low-intensity cortical ribbon. The central grey nuclei are homogeneously hypointense. Note phase-shift artifact (*arrows*) caused by flow at the foramina of Monro.

Results

Clinical Findings

The onset of seizures occurred within 24 hours of birth in nine patients, between 25 and 72 hours in five, and on the sixth day of life in one. Seizure activity was generalized tonic-clonic in seven patients, focal clonic in six, and not specified in two patients. The cause of the seizures was hypoxic-ischemic encephalopathy (defined as 5-minute Apgar score less than 5, umbilical arterial pH less than 7.00, respiratory depression requiring assisted ventilation, and neurologic symptomology) in three patients (Table 2), and group B streptococcal meningitis in three patients. One patient had known prenatal exposure to cocaine. There were nine patients in whom there was no identifiable cause of the seizures. There were no patients with congenital heart disease, obvious birth trauma, coagulopathy, or metabolic abnormalities known to be associated with neonatal seizures.

MR Findings

Using the criteria stated above, MR findings were normal in three patients and abnormal in 12. The abnormalities were characterized as either focal or diffuse.

TABLE 2: Comparison of clinical features and imaging

Patient	Apgar (1/5 min)	Umbilical Cord pH	Site of US Abnormalities	Site of MR Abnormalities	Follow-Up MR	Clinical Follow-Up	Duration of Follow-Up
1	8/9	>7.3	None	None		Normal	Lost to follow-up after 6 months
2	1/6/7[a]	6.84	None	None		Normal	Lost to follow-up after 6 months
3	1/2/2[a]	7.0	None	None		Normal	24 months
4 (Figs 2A–2D)	7/9	>7.3	Right FTP, right basal ganglia	Right FTP, right basal ganglia, thalamus and brain stem	Infarct right middle cerebral artery, atrophic right basal ganglia and brain stem	Spastic left hemiplegia, seizures, developmental delay	12 months
5	7/9	>7.3	Left thalamus	Left thalamus	Gliosis left thalamus	Normal	13 months
6	5/8	>7.3	Left PT	Left PT		Mild right hemiparesis	8 months
7 (Figs 3A–3C)	9/9	7.26	Left FT	Left PF	Infarct left FT region	Normal	11 months
8	8/9	>7.3	Left putamen, periventricular white matter	Left putamen, periventricular white matter		Normal	Lost to follow-up after 7 months
9 (Figs 4A–4B)	7/9	7.31	Cerebral edema, bilateral basal ganglia, thalami	Cortex, white matter, bilateral basal ganglia and thalami		Spastic hemiplegia, seizures, developmental delay	12 months
10 (Figs 5A–5D)	7/9	>7.3	Left FT, right basal ganglia, ventriculomegaly	Diffuse cerebral edema, left FTP, bilateral basal ganglia and thalami	Infarct left FTP, atrophy left basal, thalamus, global white matter, delayed myelination	Right hemiplegia, seizures, developmental delay	Lost to follow-up after 8 months
11	9/9	>7.3	Cerebral edema, basal ganglia, thalami	Cortex, white matter basal ganglia, and thalami		Spastic quadraparesis, seizures, developmental delay	Lost to follow-up after 9 months
12	6/7/5*	7.24	Cerebral edema	Cortex, white matter bilateral basal ganglia and thalami	Biparietooccipital atrophy, global white matter, delayed myelination	Spastic quadraparesis, developmental delay	12 months
13 (Figs 6A–6C)	8/9	>7.3	None	Hemispheric white matter, basal ganglia, thalami, and left mesencephalus	Autopsy; encephalomalacia with gliosis	Spastic quadraparesis, seizures	7 weeks
14 (Figs 7A–7C)	8/9	7.19	Cerebral edema	Hemispheric white matter		Normal	14 months
15	6/9	7.09	Bifrontal white matter, intraventricular hemorrhage	Bifrontal white matter, intraventricular hemorrhage, thrombosed superior sagittal sinus	CT, bifrontal atrophy, shunted hydrocephalus	Normal	13 months

Note.—F indicates frontal; T, temporal; and P, parietal.

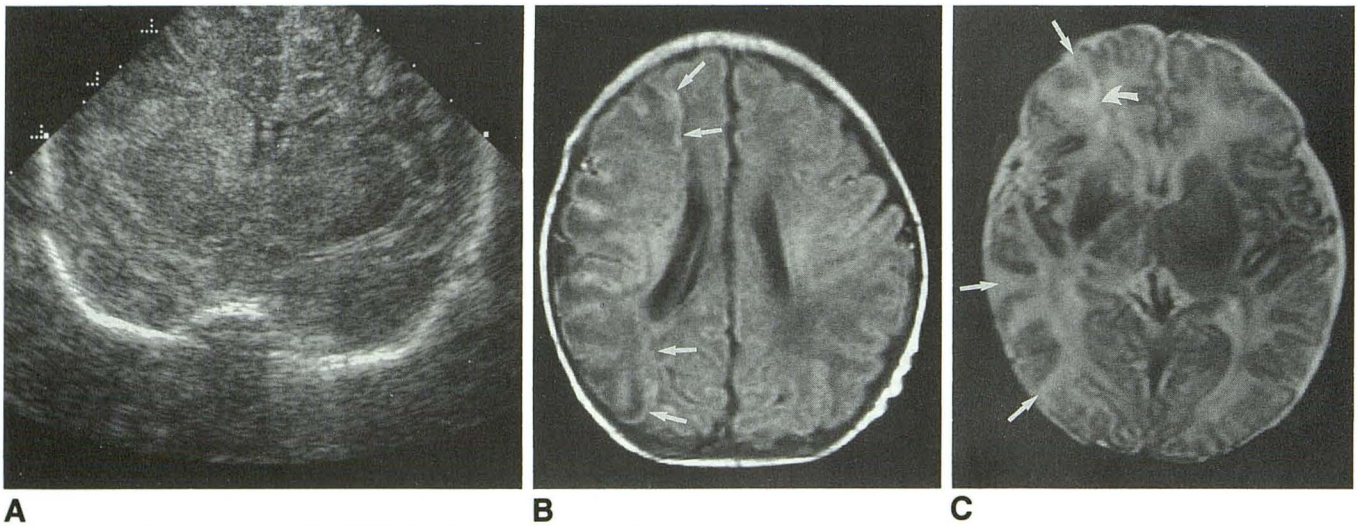
[a] Ten-minute Apgar scores.

Focal Injury

Five patients had focal ischemic injury which was hyperintense on T1-weighted images in five patients, hypointense on T2-weighted images in three, and hyperintense on T2-weighted images in two. One of the five patients had increased T2 signal within the right cortical ribbon and regional white matter, ipsilateral basal ganglia, and corticospinal tract (Figs 2A–2D). MR at 12 months of age showed a large right infarct of the middle cerebral artery with wallerian degeneration of the brain stem. The second patient had T1 shortening within the left thalamus with a corresponding area of increased T2 signal. MR at 12 months of age showed gliosis within the thalamus. Two patients had ischemic injury in a left middle cerebral artery distribution; of these, one showed T2 shortening (Figs 3A–3C), and one showed T2 prolongation. One of these two patients underwent imaging at 7 months of age; findings revealed a cortical infarct corresponding to the site of abnormality on the previous MR. The fifth patient had increased T1 signal within the left putamen and posterior limb of the left internal capsule with corresponding areas of T2 prolongation in the distribution of the left lateral lenticulostriate artery. Follow-up MR was not obtained in this patient.

Diffuse Injury

Six patients had diffuse cerebral injury seen at MR as multiple focal or confluent areas of T1 and T2 prolongation within the hemispheric white matter; five of these six patients had loss of the hypointense cortical ribbon on T2 images and diffuse increased T2 signal within the basal ganglia (Figs 4A and 4B). Other abnormalities included a large left middle cerebral artery infarct



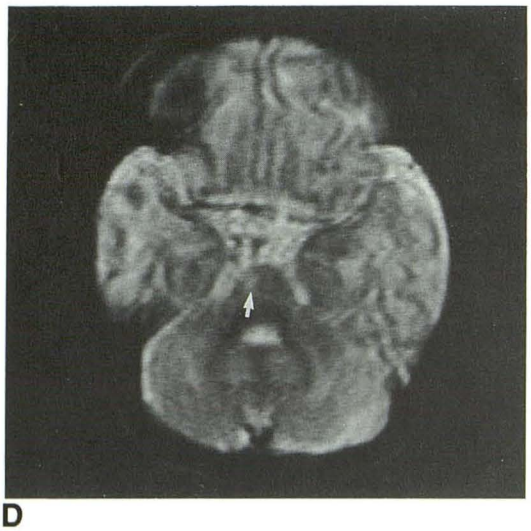


Fig. 2. Term infant, product of normal pregnancy and delivery, with left-sided seizures.

A, Coronal US shows increased echogenicity corresponding to the right middle cerebral artery distribution with involvement of the right basal ganglia.

B, Axial T1 image at 6 days of age shows T1 shortening within cortical ribbon and edematous white matter corresponding to an infarct (*arrows*) in the middle cerebral artery territory.

C, Axial T2 image shows that the cortical ribbon has focal areas of increased signal intensity (*arrows*). The right insular cortex and putamen are abnormally hypointense; the infarcted thalamus and caudate nucleus show increased T2 signal. Edema within the frontal white matter is seen as hyperintense (*curved arrow*).

D, Axial T2 image through the pons shows increased signal within the corticospinal tract (*arrow*) not visible on US. The patient had left hemiplegia, spasticity, and seizures on follow-up.

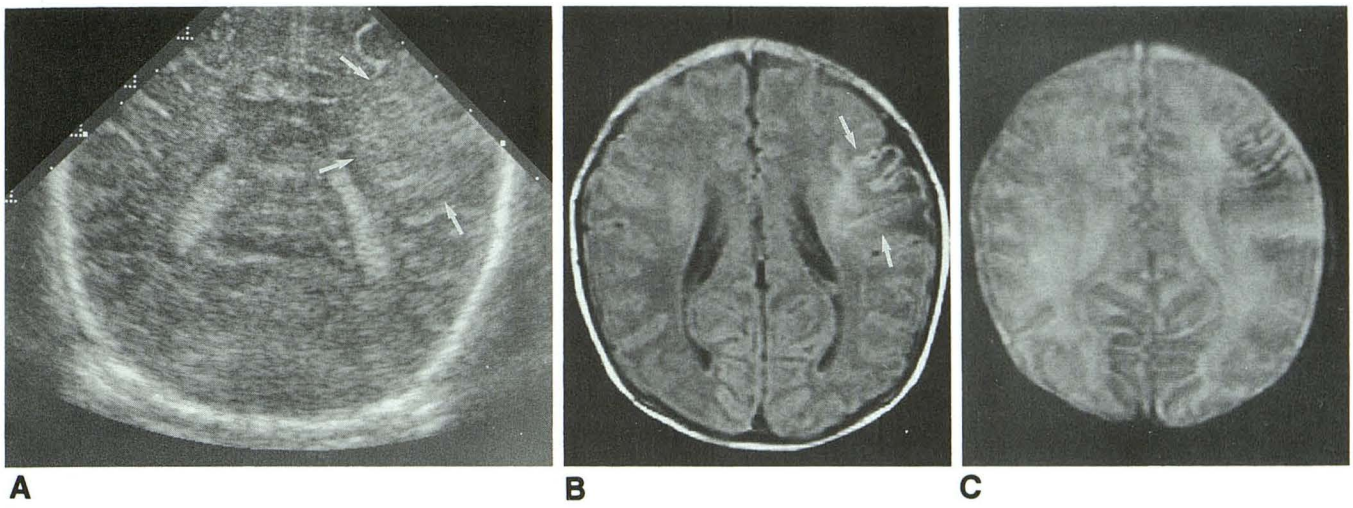


Fig. 3. Term infant with focal right-sided seizures and prenatal cocaine exposure.

A, Coronal US through cerebral convexities shows focal area of increased echogenicity (*arrows*) in the left parietal region consistent with ischemic injury.

B, Axial T1-weighted image at 9 days of age shows T1 shortening within the cortical ribbon and deep white matter; the subcortical white matter is hypointense.

C, Axial T2-weighted image shows diminished signal intensity within the infarcted cortex and regional white matter. The patient had a mild right hemiparesis which resolved at 11 months follow-up.

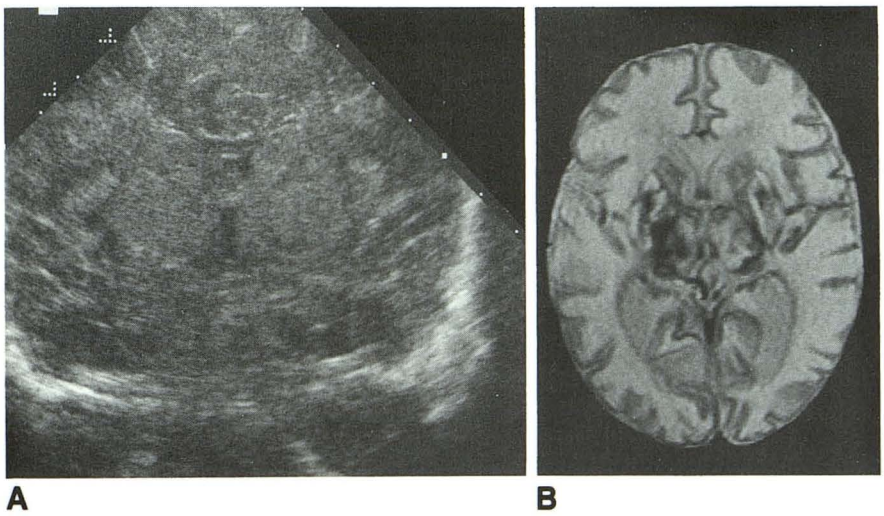


Fig. 4. Term infant, product of normal pregnancy, with generalized seizures. Labor was complicated by fetal heart rate decelerations requiring emergency cesarean section. There was diffuse cerebral injury with basal ganglia involvement.

A, Coronal US through basal ganglia shows diffuse increase in echogenicity within cerebral white matter and basal ganglia and loss of normally hyperechoic sulci.

B, Axial T2 image at 13 days of life shows grossly abnormal cerebral white matter. Compare white matter on this patient with that seen in Fig 1. Note areas of T2 shortening mixed with areas of hyperintense signal within the basal ganglia and thalami. Patient subsequently developed spastic quadriplegia and seizures and is developmentally delayed at 12 months.

in one patient (Figs 5A–5D) and increased T2 signal within the left cerebral peduncle in another patient (Figs 6A–6C). The sixth patient had edematous cerebral white matter with normal basal ganglia and brain stem (Figs 7A–7C). Follow-up MR was performed at 5 months on two of the six patients. Findings included global delay in myelination and diffuse paucity of white matter. In addition, a left middle cerebral artery infarct was noted in one patient and biparietooccipital atrophy in the other. Autopsy in the one patient who died revealed extensive neuronal depopulation and astrocytic proliferation throughout the cerebral hemispheres, basal ganglia, and brain stem.

The final patient had venous infarction and intraventricular hemorrhage secondary to superior sagittal sinus thrombosis.

Cranial US Findings

Using the criteria listed above, US findings were normal in four patients and abnormal in 11. US findings were characterized as focal or diffuse.

Focal Injury

Five patients had focal ischemic injury. US abnormalities included involvement of the right

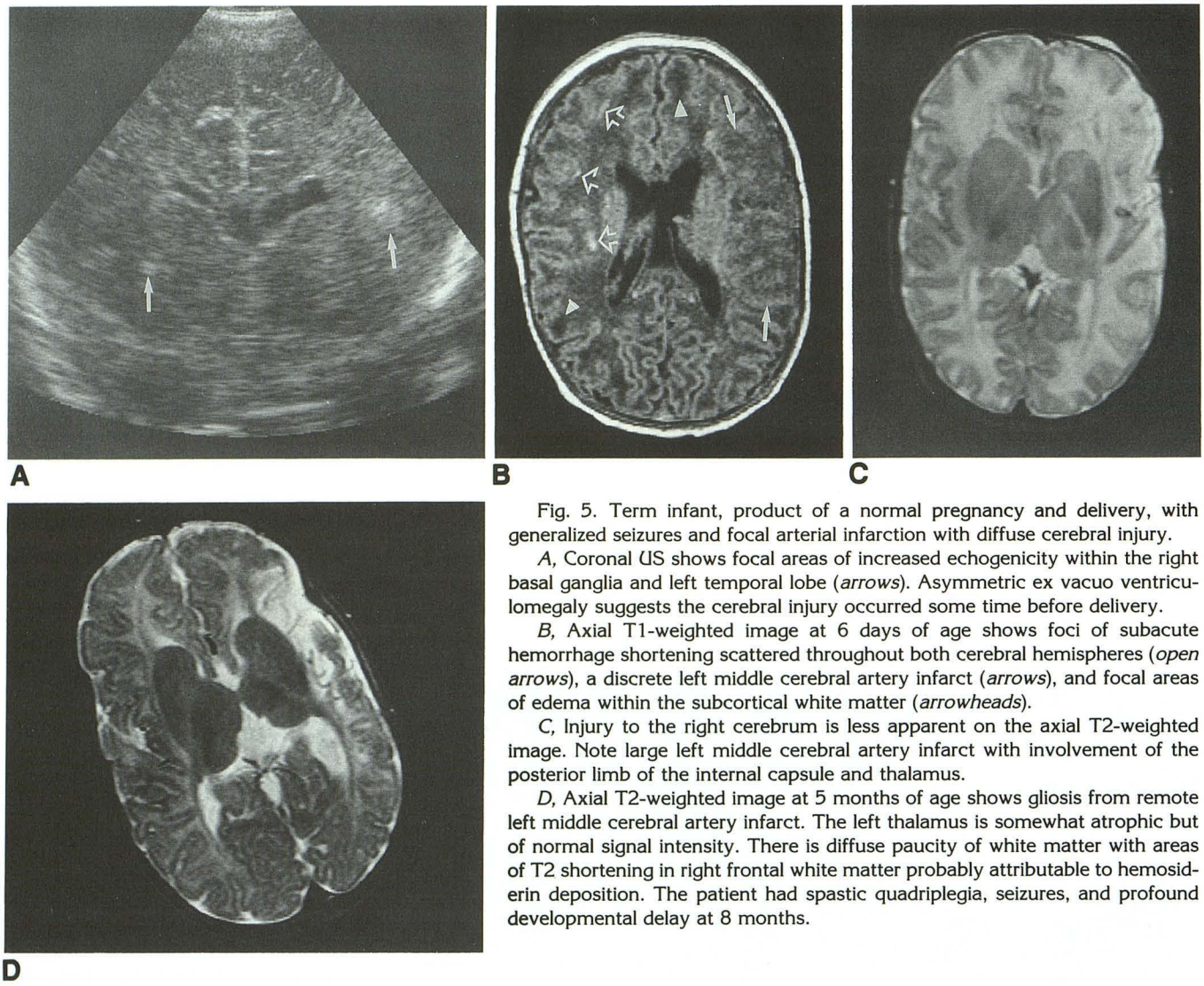


Fig. 5. Term infant, product of a normal pregnancy and delivery, with generalized seizures and focal arterial infarction with diffuse cerebral injury.

A, Coronal US shows focal areas of increased echogenicity within the right basal ganglia and left temporal lobe (*arrows*). Asymmetric ex vacuo ventriculomegaly suggests the cerebral injury occurred some time before delivery.

B, Axial T1-weighted image at 6 days of age shows foci of subacute hemorrhage shortening scattered throughout both cerebral hemispheres (*open arrows*), a discrete left middle cerebral artery infarct (*arrows*), and focal areas of edema within the subcortical white matter (*arrowheads*).

C, Injury to the right cerebrum is less apparent on the axial T2-weighted image. Note large left middle cerebral artery infarct with involvement of the posterior limb of the internal capsule and thalamus.

D, Axial T2-weighted image at 5 months of age shows gliosis from remote left middle cerebral artery infarct. The left thalamus is somewhat atrophic but of normal signal intensity. There is diffuse paucity of white matter with areas of T2 shortening in right frontal white matter probably attributable to hemosiderin deposition. The patient had spastic quadriplegia, seizures, and profound developmental delay at 8 months.

temperofrontoparietal region and ipsilateral basal ganglia in one, left thalamus in one, left frontoparietal region in two, and left posterior putamen and periventricular white matter in one. Brain stem abnormalities were not detected in any patient. Four of the five patients with focal ischemic lesions had serial US: in three of these four patients the sonographic abnormalities remained unchanged in the first 19 days; in the other patient the sonographic abnormalities became most conspicuous at day of life 9. Correlation of US and MR findings in the perinatal period is included in Table 2 as is correlation of US with MR done on three patients at 7, 12, and 13 months.

Diffuse Injury

Five patients had US findings of multifocal or diffuse cerebral injury, including diffuse cerebral edema in five, with normal basal ganglia in three and abnormal hyperechoic basal ganglia in two. There were no brain stem abnormalities in any patients. One of the five patients had asymmetric ex vacuo ventriculomegaly on the first day of life, suggesting prenatal cerebral injury. In three of the five patients, initial US findings were abnormal; in two patients, the initial cranial US findings were normal. The US findings became most visible at 4 and 5 days of age, respectively.

The patient who at MR exam demonstrated sagittal sinus thrombosis had large hyperechoic areas within the frontal lobes, with intraventricular hemorrhage and hydrocephalus on subsequent US studies.

Clinical Follow-Up

Clinical follow-up ranging from 6 to 24 months (mean 13 months) is available in 14 patients.

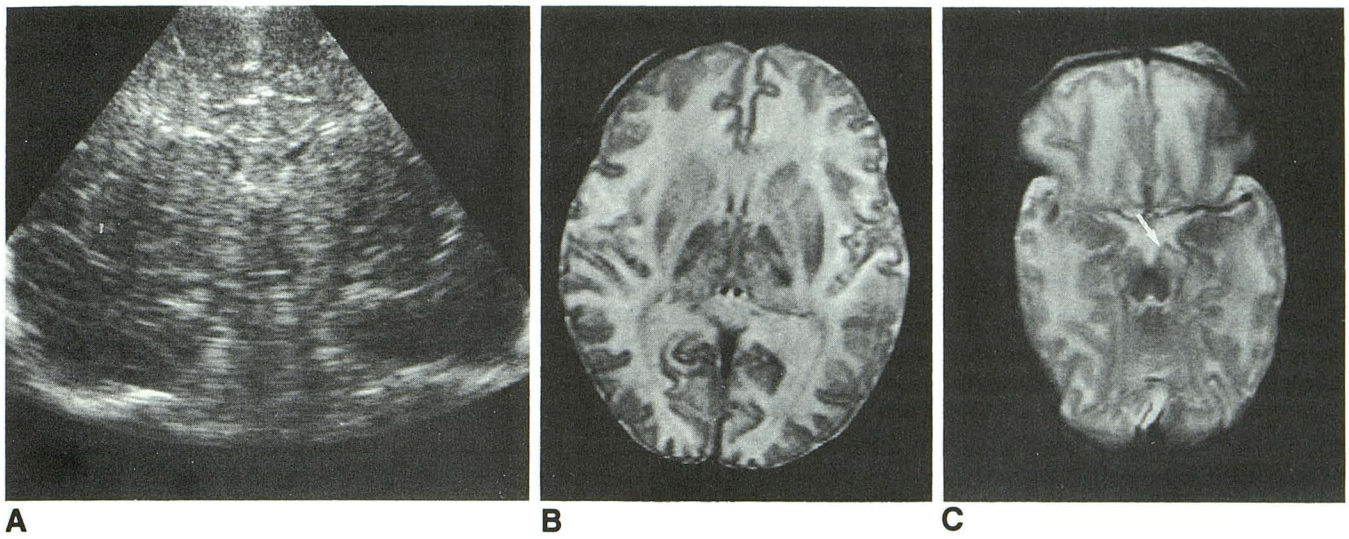


Fig. 6. Term infant with hypoxic-ischemic encephalopathy secondary to umbilical cord hematoma.

A, Coronal US from another hospital appears normal.

B, Axial T2-weighted image at 10 days of age shows edema within the cerebral white matter and internal capsules. The head of the caudate, globus pallidus, ventral putamen, and dorsal thalami are edematous.

C, Axial T2-weighted image through the brain stem shows edema within the left cerebral peduncle (*arrow*). Autopsy at 7 weeks of age revealed extensive neuronal infarction and gliosis within the cerebrum, cerebellum, basal ganglia, and brain stem.

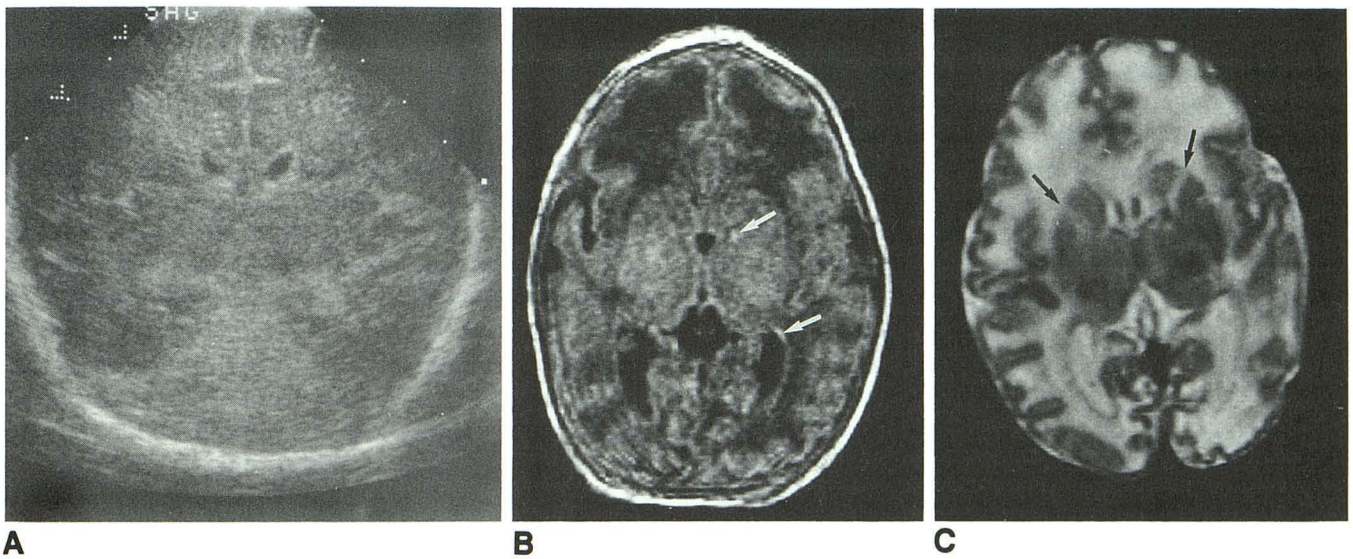


Fig. 7. Term infant with group B streptococcal meningitis and generalized seizures.

A, Coronal US shows loss of normally hyperechoic sulci but no discrete areas of abnormal echogenicity.

B, Axial T1-weighted image at 7 days of age shows abnormal low signal intensity within frontal, and to a lesser extent, posterior parietal white matter with involvement of external capsules. Note punctuate areas of subacute hemorrhage (*arrows*).

C, Axial T2-weighted image shows effacement of frontal sulci and diffuse increase in signal intensity within the cerebral white matter. Compare with Fig 1. Although the anterior limbs of the internal capsule are hyperintense (*arrows*), the central gray nuclei are normal. The patient is healthy at 14 months.

Eight patients are neurologically normal at the most recent clinical examination. Perinatal MR findings in these patients are as follows: normal in three, left thalamic infarct in one, left frontoparietal infarct in one, diffuse edema of the cerebral white matter with normal basal ganglia in one, edema within the left posterior putamen and periventricular white matter in one, and bifrontal venous infarcts in one. The latter two patients had mild hypertonicity, which persisted until 4 months of age; one infant also had right hemiparesis in the perinatal period, which resolved.

Seven patients had abnormal neurologic examinations at follow-up. One patient had a mild

right hemiparesis but has had normal developmental milestones and no spasticity. MR in the perinatal period had shown a left parietotemporal infarct with sparing of the basal ganglia. One patient has spastic hemiplegia, developmental delay, and seizures. Perinatal MR had shown a large right middle cerebral artery infarct with basal ganglia and brain stem involvement.

Of the remaining five patients, two have spastic quadriparesis, two have upper extremity spasticity, and one has hemiplegia with nystagmus. Two of these patients continue to have seizures; three have significant delay in developmental milestones. MR findings in the perinatal period showed diffuse cerebral and basal ganglia abnormalities.

Statistical Analysis

By Fisher Exact Test, there was no statistically significant association between perinatal risk factors such as Apgar scores, umbilical cord pH, meconium staining, and structural abnormalities at imaging or subsequent neurologic morbidity. The association between MR evidence of diffuse cerebral injury and an abnormal neurologic outcome was significant ($P = .001$). There was also a significant association between MR evidence of basal ganglia and brain stem injury and an abnormal clinical outcome ($P = .032$).

Compared with MR, the sensitivity and specificity of US in detecting basal ganglia injury were 38% and 100%, respectively.

Discussion

Seizures are the most common manifestation of cerebral injury in the neonate (1, 5). The patients in this study were selected on the basis of neonatal seizures. Seventy-five percent had MR abnormalities suggesting focal or diffuse edema and/or infarction.

The signal intensity of focal cerebral ischemia in term infants is reported as T1 and T2 shortening, suggesting hemorrhage (6). We observed this pattern in three patients. However, there were two patients in whom the focal ischemic lesions showed increased T2 signal. The variable signal intensity of the focal ischemic lesions on T2 images does not appear to be related to evolving hemorrhage because there was no correlation between time elapsed since the onset of seizures and the signal characteristics of the ischemic lesions. A nonheme mechanism for the T1 shortening may be breakdown of macromolecular proteins into smaller fragments, which occurs with cerebral infarction and laminar necrosis (7).

The MR appearance of diffuse cerebral injury in our series of patients differed from that seen in focal ischemic lesions. The predominant pattern of signal intensity among the six patients with diffuse cerebral injury was T1 and T2 prolongation attributable to increased brain water, although three patients had punctate areas of T1 shortening suggesting subacute petechial hemorrhage. The patients with focal ischemic injury underwent MR imaging earlier after the onset of seizures than did the patients with diffuse cerebral injury (7.6 versus 12.1 days), because the latter group of patients were much sicker. Although the differences in signal intensity in focal as compared with diffuse injury may be attributable to evolving intraparenchymal hemorrhage, a more plausible explanation is a different pathophysiologic mechanism of injury. The focal ischemic lesions conform to an arterial distribution suggesting an embolic or thrombotic event. Autopsy and imaging studies have shown that focal cerebral infarction in neonates is most often caused by arterial occlusive disease, usually embolic, with a predilection for the left middle cerebral artery (8, 9, 10). Although focal arterial infarction may be caused by hypoxic-ischemic encephalopathy, in many cases a clear causal mechanism cannot be identified (10, 11). In contrast to focal infarction, diffuse cerebral injury is thought to be caused by prolonged hypoxia or total asphyxia (1, 12). Prolonged hypoxia with hypotension results in cerebral hypoperfusion, destruction of the cortex, and subcortical white matter and watershed infarcts. Arterial flow to the basal ganglia, thalami, and brain stem is preserved. When total asphyxia occurs, there is complete cessation of intracranial arterial flow with resultant infarction of the areas of greatest metabolic demand, the basal ganglia, thalami, and brain stem (1, 12). Only one patient in our study who had MR findings consistent with prolonged hypoxia or total asphyxia had clinical signs or symptoms of perinatal distress, suggesting that further study is needed to identify prospectively neonates at risk for diffuse cerebral injury.

According to some reports, cerebral injury is caused by hypoxia or ischemia in nearly 70% of neonates with seizures (1). Other studies have concluded that the proportion of newborn cerebral injury attributable to hypoxic or ischemic

injury remains unknown and have suggested that the diagnosis of hypoxic-ischemic encephalopathy should be avoided unless criteria by which hypoxic-ischemic encephalopathy is defined are fulfilled (5). Other causes of neonatal seizures include infections, birth trauma, metabolic derangements, congenital malformations, and neurophakomatoses (1). Neonatal encephalopathy and seizures may occur in the absence of identifiable risk factors (11). Because hypoxic-ischemic encephalopathy has significant medicolegal implications, the absence of identifiable risk factors should not implicate hypoxic-ischemic encephalopathy by default (5).

In our series of patients, hypoxic-ischemic encephalopathy was identified as the cause in only three of 15 patients. Three patients had bacterial meningitis, and one was exposed to cocaine in utero. The remaining nine patients had no identifiable risk factors or perinatal distress, suggesting that markers of perinatal distress are insensitive or that the cerebral insult occurred sometime before the delivery. We found that the criteria by which hypoxic-ischemic encephalopathy is defined (eg, a persistently low Apgar score, meconium staining of amnionic fluid, severe fetal acidosis, and the need for assisted ventilation) did not correlate with presence or pattern of cerebral injury on MR or subsequent neurologic morbidity. Of the three patients with clinical signs of hypoxic-ischemic encephalopathy, two had normal imaging studies and are neurologically normal at short-term follow-up, and one had diffuse cerebral injury with basal ganglia and brain stem involvement and died at 7 weeks of age with spastic quadriplegia. Because neurologic morbidity may be clinically occult until the child reaches school age, it is premature to state that the patients who are healthy at short-term follow-up will remain so (1). Two patients who had abnormal neurologic examinations in the perinatal period were healthy at follow-up, suggesting that some abnormal perinatal neurologic signs may resolve with time.

The acute response of the neonatal brain to toxic, ischemic, or traumatic injury is a nonspecific increase in echogenicity by cranial sonography (4). The mechanism of increased echogenicity in edematous brain is unknown (4). US does not permit accurate differentiation of parenchymal hemorrhage from infarction, necrosis, or edema (4). Regardless of its relative lack of specificity, US is sufficiently sensitive to intraventricular hemorrhage and parenchymal injury to be standard care in sick neonates. The role of cranial US in term neonates with seizures is not well defined. In our intensive care unit, cranial US has been the initial and frequently the only modality used for imaging of neonates with seizures or encephalopathy. Clinical and autopsy studies have shown that US underestimates cortical and basal ganglia injury; therefore, a normal cranial US does not assure a normal neurologic outcome (13, 14). We observed that US seems to be more sensitive to focal ischemic injury within the cerebral hemispheres than to diffuse cerebral edema or infarction. Compared with MR, focal ischemic injury was consistently detected by US, but diffuse cerebral injury was either missed or underestimated in the majority of patients. However, the variable time between the most recent US and the MR precludes direct comparison between the two modalities.

In reviewing the US, we found focal ischemic injury tended to be most conspicuous on the initial US performed within 24 hours of onset of seizures and remained so for 8 days or more. In diffuse cerebral injury, the temporal evolution of US findings was less predictable. Although three patients had US abnormalities that were readily apparent on the initial studies, two patients with diffuse cerebral edema initially had normal US. The US abnormalities became most apparent at days 4 and 5 of life, respectively, and diminished on subsequent studies. The pattern of sonographic evolution in diffuse cerebral injury suggests that MR should not necessarily be compared with the US study performed most closely in time, but rather to the US study that is most abnormal during the perinatal course.

We found that US was more sensitive to the presence of unilateral basal ganglia injury than to bilateral basal ganglia injury. The relative insensitivity of US to bilateral basal ganglia injury may be attributable to the lack of a normal side for comparison or to the presence of edema rather than infarction. US was unable to show brain stem injury in the two patients found to have brain stem abnormalities by MR. Like basal ganglia injury, brain stem injury correlates with adverse neurologic outcome (10). The presence of basal ganglia and brain stem injury not apparent with US may explain in part why some infants with normal perinatal US have abnormal neurologic outcomes (13, 14).

One of the patients with diffuse cerebral injury had MR imaging repeated on day 12 of life. Compared with the MR done on the fourth day

of life, the findings were most conspicuous on the later study, 11 days after the onset of generalized seizures. Serial MR studies were not considered feasible because of cost and the need for transport of sick infants. However, the changing pattern of MR findings in this one patient suggests that the time at which MR is most sensitive to pathologic brain water in the neonate is not known. Autopsy in the one patient with diffuse brain injury who died at 7 weeks of age revealed considerably more parenchymal destruction in the brain stem than was apparent on MR done earlier. Possible explanations for the disparity between MR and autopsy findings include ongoing ischemic insult, MR imaging performed outside the window of maximum sensitivity, and lack of sensitivity of midfield MR to subtle brain stem abnormalities. In the absence of autopsy confirmation, the sensitivity of MR to brain stem injury in neonates is not known and warrants further study.

When further imaging is indicated in full-term infants with abnormal cranial US, we usually prefer MR over CT. Although Barkovich has suggested that CT is more sensitive than MR in the first 24 hours after anoxic injury (12), we do not as a rule image anoxic infants so soon after birth; none of the patients in this series underwent MR imaging within the first day of life. Our preference for MR is based on reports in the literature that have compared US, CT, and MR in neonates (6, 15). Keeney et al reported 33 neonates with hypoxic-ischemic encephalopathy and prospectively compared the findings at MR with CT and MR with US (6). Compared with MR, CT missed three of four cases of periventricular leukomalacia, two of three cases of basal ganglia hemorrhage, and five of nine cases of parenchymal hemorrhage. Compared with MR, US missed two of 12 cases of periventricular leukomalacia, one of five cases of basal ganglia hemorrhage, and four of seven cases of focal parenchymal hemorrhage. In another study, McArdle et al prospectively compared MR and CT of intracranial hemorrhages occurring in infants (15). The authors concluded that although CT and US were superior to MR in the first few days after the parenchymal hemorrhage, after 3 days MR was the single best modality (15).

The relatively small number of patients in this study and the short duration of clinical follow-up precludes definitive statements about the ultimate contribution MR will have in identifying neonates with seizures who are at risk for significant neurologic morbidity. Further investigation into clinical risk factors of neonatal encephalopathy and seizures is needed in hopes of allowing earlier, possibly prenatal, therapeutic intervention to diminish morbidity.

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