Ischaemic and haemorrhagic brain lesions in newborns with seizures and normal Apgar scores

Eugenio Mercuri, Frances Cowan, Mary Rutherford, Dominique Acolet, Jacqueline Pennock, L Dubowitz

Abstract
Serial ultrasound scans and conventional and diffusion weighted magnetic resonance imaging (MRI) were performed on 16 neonates who presented with seizures. The Apgar scores were normal and subsequently no metabolic or infective cause could be found. The aim of the study was to evaluate the extent to which early sequential imaging can elucidate the cause of seizures in apparently neurologically normal infants.

Fourteen of the infants had haemorrhagic or ischaemic lesions on MRI and these were detected by ultrasound scanning in 11. Early ultrasound scanning detected the haemorrhagic lesions but the ischaemic lesions were often not seen until the end of the first week of life. Early MRI, however, was able to detect all the ischaemic lesions. The evolution of the insult could be timed by using serial ultrasound scans and a combination of diffusion weighted and conventional MRI during the first week of life, confirming a perinatal insult even in the absence of fetal distress.

Although the aetiology of these lesions remains obscure, serial ultrasound scans will detect the presence of cerebral lesions in neonates presenting with isolated seizures but additional MRI sequences will give better definition on type, site, and extent of the pathology. (Arch Dis Child 1995; 73: F67-F74)

Keywords: newborn, convulsions, MRI, ultrasound.

Seizures are considered one of the most common clinical manifestations of central nervous system (CNS) disorders in the neonatal period,1 with a reported incidence from 1-5 to 14/1000 livebirths.2 The precise incidence has been difficult to establish as the neonatal populations studied are not comparable and also because many ‘subtle’ seizures can easily escape detection.

Many seizures have no identifiable cause and are thought, in some cases, to be benign. Metabolic disorders, infections, and trauma are common causes, but the best documented cause is hypoxic-ischaemic encephalopathy (HIE), usually secondary to perinatal asphyxia. It has been reported, however, that seizures can be the first sign of haemorrhagic or ischaemic lesions sustained in the perinatal period in infants who do not show any identifiable risk factor or signs of HIE after birth.3-6 Various techniques have been used to investigate infants with seizures. The electroencephalogram (EEG) is of value in identifying and defining the extent of the seizures,7,8 but a normal EEG cannot exclude the presence of a lesion and abnormal activity is not always pathognomonic of specific structural lesions. Cranial ultrasound scanning has become a routine examination in newborns at risk of cerebral injury, but its value in full term newborns is still debatable.9,10 Computed tomography may provide more detailed information, but its serial use is limited by the potential risk of irradiation and the images obtained do not give the same detail as magnetic resonance imaging (MRI). Due to the improvement of techniques more suitable for imaging the infant’s brain and for monitoring infants during the examination, MRI is now accepted as the imaging method of first choice11 for following up the normal and abnormal changes in the developing brain.

A recent imaging study of neonatal seizures highlighted the usefulness of ultrasound scans and MRI in infants presenting with seizures.3 The aim of our study was to evaluate the extent to which early sequential imaging can elucidate the cause of seizures in infants with normal Apgar score and normal neurology before the onset of seizures. We hoped, using different modalities, to be also able to time the onset of any lesion found and to provide information about the optimal imaging schedule to undertake in this clinical situation.

Methods
This study is part of an ongoing longitudinal MRI and clinical study aimed at documenting the evolution of neonatal cerebral lesions. As part of this, all the infants with convulsions, with or without HIE, are imaged. The study has been approved by the Research Ethical Committee of the Royal Postgraduate Medical School. Consent was obtained from the parents as soon as possible after the admission of their babies. Criteria for inclusion in the present study were infants born at term with (i) Apgar scores of 8 or more at 5 minutes; (ii) those who presented with seizures in the first four days of life; and (iii) those who had no apparent abnormal neurological signs until the onset of seizures.

Details of the pregnancy, perinatal period, and description of the seizures were obtained from the parents and/or from the obstetric and paediatric records of each patient. Neurological examination was performed and recorded on a standardised proforma12 soon...
after admission and repeated at least weekly.

All the infants had a routine metabolic screening, which included blood glucose concentrations, calcium, magnesium, ammonia, bilirubin and blood and urine concentrations of organic and amino acids.

The routine screening for infections included white cell count and C-reactive protein concentrations and, in infants with suspicion of sepsis, lumbar puncture.

Continuous EEG was recorded using a four channel Oxford Medilog from F3–P3 and F4–P4 using silver/silver chloride electrodes. Recordings started as soon as possible after the onset of the seizures or after the admission for the infants referred.

BRAIN IMAGING

Cranial ultrasound scanning

Ultrasound scans were performed within 24 hours of the onset of seizures with an Advanced Technology Laboratory (ATL) mark IV sector scanner, using a 5 and 7.5 MHz probe. The scans were assessed for normal anatomy, ventricular size, and evidence of focal or diffuse increased echogenicity within the cerebral hemispheres and basal ganglia.

MRI scans

The infants were imaged on a 1.0 Tesla Picker HPQ system using conventional T1 weighted spin echo (SE 860/20 ms), inversion recovery (IR 3800/30/950), and T2 weighted spin echo (SE 3000/120 ms) sequences. Seven infants also had diffusion weighted imaging, using a cardiac gated pulsed gradient spin echo sequence (SE pulse interval/200 ms) with diffusion sensitivity parameter (b) of 600 s/mm² and four data acquisitions. These were applied in two or more perpendicular planes.

The images were examined for normal anatomical features, ventricular size, and evidence of focal or diffuse abnormalities within the cerebral hemisphere and basal ganglia. The diffusion weighted images were also assessed for abnormal high signal and loss of anisotropy.

If possible, the infants were examined during natural sleep; if not, they were sedated with oral or rectal chloral hydrate (30–50 mg/kg).

Follow up clinical assessment included serial neurological examinations recorded on a standardised proforma and on videotape. The infants were seen at three monthly intervals until one year, at six monthly intervals until 2 years of age, and yearly thereafter.

Results

INITIAL CLINICAL ASSESSMENT

Twenty seven infants, born in or referred to the neonatal unit of the Hammersmith Hospital, London, in the period between January 1991 and April 1994, had seizures in the first week of life. Eleven of the 27 were excluded from this study because they presented with signs of HIE. Sixteen infants fulfilled the inclusion criteria. Their gestational ages ranged from 37 to 43 weeks. The pregnancy was uneventful in all the mothers. There was no evidence of fetal distress in nine of the 16 infants. Cardiotocograph (CTG) late decelerations were present in two infants, meconium stained liquor was present in three, and both CTG late decelerations and meconium were present in the remaining two. Apgar scores below or equal to 5 at 1 minute were recorded in three infants but their score was above or equal to 8 at 5 minutes. Neurological abnormalities were not noted until the onset of seizures, but a review of the notes showed that transient apnoeic episodes had been noted in five infants. Seizures were noted to occur within the first 24 hours of life in six infants, between 24 and 48 hours in eight, between 48 and 72 hours in one, and between 72 and 96 hours in one. Eleven infants had mainly focal clonic and five generalised clonic seizures.

There was no evidence of CNS infections or known metabolic disorders which could have accounted for seizures in any of the infants.
Continuous EEG was recorded in 14 of the 16 infants. This was normal in four, and showed electrical seizures in 10, unilateral in 5, and bilateral in the other five (table 1).

**Table 2** Individual results on ultrasound scanning, conventional MRI, and diffusion weighted imaging

<table>
<thead>
<tr>
<th>Case No</th>
<th>Ultrasound scan</th>
<th>MRI</th>
<th>Diffusion</th>
<th>Follow up of lesions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D1-5</td>
<td>D6-20</td>
<td>D1-5</td>
<td>D6-10</td>
</tr>
<tr>
<td>1</td>
<td>D1: normal</td>
<td>D17: normal</td>
<td>D1: normal</td>
<td>D1: normal</td>
</tr>
<tr>
<td>2</td>
<td>D2: density in the lentiform; PV flares</td>
<td>D8: persistent</td>
<td>D3: low SI in anterior PV white matter</td>
<td>D7: left MCA infarct</td>
</tr>
<tr>
<td>3</td>
<td>D3: normal</td>
<td>D6: right posterior density</td>
<td>D6: left MCA infarct, right sylvian fissure density</td>
<td>D5: left MCA infarct, haemorrhage, left lentiform, abnormal SI in left ALIC and PLIC, smaller right MCA infarct</td>
</tr>
<tr>
<td>4</td>
<td>D4: normal</td>
<td>D8: right MCA infarct</td>
<td>D8: left MCA infarct</td>
<td>D9: left MCA infarct</td>
</tr>
<tr>
<td>5</td>
<td>D5: normal</td>
<td>D6: left MCA infarct, right sylvian fissure density</td>
<td>D5: left MCA infarct, haemorrhage, left lentiform, abnormal SI in left ALIC and PLIC, smaller right MCA infarct</td>
<td>D2: definite left MCA infarct</td>
</tr>
<tr>
<td>6</td>
<td>D6: normal, D5: left MCA infarct</td>
<td>D8: left MCA infarct, right sylvian fissure density</td>
<td>D9: more obvious</td>
<td>D2: left MCA infarct</td>
</tr>
<tr>
<td>7</td>
<td>D7: normal</td>
<td>D8: left MCA infarct</td>
<td>D8: no change</td>
<td>D4: left MCA infarct</td>
</tr>
<tr>
<td>8</td>
<td>D8: normal</td>
<td>D6: left parieto-occipital infarct</td>
<td>D6: no change</td>
<td>D8: no change</td>
</tr>
<tr>
<td>9</td>
<td>D9: normal</td>
<td>D6: left MCA infarct</td>
<td>D6: no change</td>
<td>D8: no change</td>
</tr>
<tr>
<td>10</td>
<td>D10: normal</td>
<td>D6: left MCA infarct</td>
<td>D2: right MCA infarct</td>
<td>D2: right MCA infarct</td>
</tr>
<tr>
<td>11</td>
<td>D1: normal</td>
<td>D1: substantial brain swelling infarction of both hemispheres with sparing of left occipital lobe</td>
<td>D3: decrease in brain swelling minimal change</td>
<td>D1: diffuse loss of anisotropy in regions of infarction, D3: minimal change</td>
</tr>
<tr>
<td>12</td>
<td>D2: left MCA infarction</td>
<td>D2: left MCA infarction</td>
<td>D2: loss of anisotropy in cortex, D5: spread to involve white matter</td>
<td>D2: loss of anisotropy in cortex, D5: spread to involve white matter</td>
</tr>
<tr>
<td>13</td>
<td>D3: normal</td>
<td>D8: basal ganglia lesion</td>
<td>D8: left lentiform haemorrhage involvement of left PLIC and external capsule</td>
<td>D8: left lentiform haemorrhage involvement of left PLIC</td>
</tr>
<tr>
<td>14</td>
<td>D4: density MCA region, parasagittal lesion, D5: scattered echodensities</td>
<td>D9: normal</td>
<td>D5: left lentiform haemorrhage involvement of left PLIC and external capsule</td>
<td>D5: left lentiform haemorrhage involvement of left PLIC</td>
</tr>
<tr>
<td>15</td>
<td>D5: normal, D4: odd left sylvian fissure and left GLH</td>
<td>D5: Bilateral haemorrhagic lesion DWM in CSO, Abnormal SI in anterior part of left PLIC</td>
<td>D5: loss of anisotropy in haemorrhagic lesion, Abnormal SI in anterior part of left PLIC</td>
<td>D5: loss of anisotropy in haemorrhagic lesion, Abnormal SI in anterior part of left PLIC</td>
</tr>
<tr>
<td>16</td>
<td>D6: right venous infarction, right GLH</td>
<td>D5: right haemorrhagic lesion in left occipital lobe, right GLH</td>
<td>D6: left small parenchymal haemorrhage in CSO</td>
<td>D6: left small parenchymal haemorrhage in CSO</td>
</tr>
</tbody>
</table>

D=day; PV=periventricular; SI=signal intensity; MCA=middle cerebral artery; m=months; SAH=subarachnoid haemorrhage; ALIC=anterior limb internal capsule; PLIC=posterior limb internal capsule, GLH=germinal layer haemorrhage.

**BRAIN IMAGING**

Imaging was performed as soon as possible after the onset of seizures and admission (mean time 1-5 days for ultrasound scan and 3-4 days for MRI). One infant had normal ultrasound and MRI scans. Cerebral infarction in the territory of a major cerebral artery was seen in 10 infants, definite basal ganglia lesions were seen in one infant, and a doubtful lesion in the lentiform on ultrasound scanning in one. Haemorrhagic lesions were seen within the white matter in three. Details of the ultrasound scan and MRI findings and timing are shown in table 2.

**Infarction in a major cerebral artery (n=10).**

Seven infants had unilateral infarcts (five on the left and two on the right), three had bilateral infarcts.

**Ultrasound scan**

Localised densities consistent with infarction were detected on the initial scan (day 1 to day 5) in four of the 10 infants and another had localised densities which were not characteristic of infarction. One of the infants with signs of infarction on early ultrasound scanning died on day 3. After day 5 localised densities consistent with infarction (fig 1) could be identified in eight of the nine surviving infants.

**Initial MRI scan**

**Conventional MRI sequences.** Eight of the 10 infants with infarction were scanned in the first five days of life. Localised changes in the territory of the middle cerebral artery suggestive of infarction—that is, low signal on T1 with loss of grey/white matter differentiation (fig 2A).
and high signal on T2, were seen in six of the eight. After day 5 regions of infarction were clearly identified in all infants (fig 2D).

Diffusion weighted imaging. Seven infants had diffusion weighted imaging in the first five days: increased signal intensity with loss of anisotropy was seen on all the seven (figs 2B, C). These appearances were still present after day 5 but were less obvious (fig 2E).

Follow up scans
Follow up MRI scans between one and 15 months showed loss of tissue at the site of infarction but the areas of involved tissue appeared smaller than on the neonatal scans (fig 2F). In one infant (case 7) it was difficult to recognise the site of the previous infarct, although there was some widening of the sulci in the region that had been abnormal.

Basal ganglia lesions (n = 2). Two infants had basal ganglia lesions.

Ultrasound scan
One infant had a normal initial scan on day 4 but showed unilateral densities in the lentiform nucleus on day 8 (case 13) (fig 3). The second showed unilateral density in the lentiform and periventricular white matter on day two and day nine (case 2).

Initial MRI scan
Conventional MRI. One infant showed a haemorrhagic infarct in the left lentiform nucleus and left body of the caudate on day eight (case 13) (fig 4A). The second showed an area of low signal intensity in the anterior periventricular white matter but no basal ganglia lesions (case 2).

Diffusion weighted imaging. In one infant (case 13) on day 8 this showed the basal ganglia lesions and, in addition, an extension of the lesion into the anterior portion of the posterior limb of the internal capsule on the affected side. In the other infants (case 2) the diffusion weighted imaging was normal.

Follow up scans
Follow up scans showed cystic change with a decrease in size at the site of the original lesion in the first infant (case 13) (figs 4B, C); this was normal in the other (case 2).

Haemorrhagic lesions in white matter (n = 3). Three infants had haemorrhagic lesions in the white matter.

Ultrasound scans
One infant (case 14) had parasagittal densities, with more pronounced densities in the middle cerebral artery (MCA) territory on the initial scan on day 4 (fig 5). Serial scans showed resolution of the lesions by day 9. The second (case 15) had a normal scan on day 2 but a left germinal layer haemorrhage (GLH) and densities in the sylvian fissure were present on day 4. The third (case 16) showed a right GLH and changes in the region adjacent to the right frontal horn consistent with venous infarction on day 5.

Initial MRI
Conventional MRI. One infant showed periventricular and parasagittal haemorrhagic changes on MRI on days 5 and 8, confirming the ultrasound scan findings (case 14) (Figs 6A, B). However, there was no evidence of MCA involvement. The second infant, who had a GLH and sylvian fissure abnormalities on ultrasound scan (case 15), showed focal parenchymal haemorrhage on day 6. GLH and deep haemorrhagic infarction adjacent to the frontal horn were seen on day 5 in the third infant with ultrasonographic evidence of venous infarction (case 16).

Diffusion weighted imaging. This was performed on day 5 on the infant with parasagittal changes (case 14) and showed white matter lesions which had already been apparent on conventional MRI scans.

Follow up scans
The child with parasagittal lesion and focal parenchymal haemorrhages (case 14) showed slight periventricular increased T1 signal on an MRI repeated at three months (fig 6C), while case 15 had a normal scan at 1 year of age. The child with venous infarction (case 16), showed a small porencephalic cyst in the area of the infarct on the MRI repeated at nine months.

CLINICAL FOLLOW UP
The duration of follow up was between six months and three years eight months. One infant died at 3 days of age. A post mortem examination confirmed bilateral extensive cerebral infarction and clots in the internal carotid
Brain lesions in newborns with seizures

Figure 2. Boy (case 6) examined aged 43 hours. T1 weighted spin echo (SE 82/20) sequence (A), diffusion weighted image (SE pulse interval 200 ms, anterior-posterior sensitisation, b = 600 s/mm²) (B) and head foot sensitisation (C). Brain swelling is present and there is some low signal intensity in the posterior part of the parietal lobe (A). The region of infarction is clearly seen as increased signal intensity with loss of anisotropy (B) and (C). Four days later inversion recovery (IR 3800/30/950) (D) and diffusion weighted image with anterior posterior sensitisation (E). The region of infarction is readily seen in (D) and less well seen in (E). Aged 6 months, inversion recovery (IR 3400/30/800) sequence (F). There is a widened sylvian fissure on the left and the level of myelination is less in the region of infarct.
Discussion

The aim of this study was to investigate the value of early, sequential ultrasound scan and MRI in elucidating the aetiology of neonatal seizures in infants with normal Apgar scores. We also addressed the issue of timing the onset of any lesion found in an attempt to provide information about the optimal imaging schedule to undertake in this clinical situation.

Our results showed that 14 of the 16 infants studied had evidence of either ischaemic or haemorrhagic cerebral lesions. Only two infants had normal imaging. Although it has already been recognised that seizures can be the first sign of haemorrhagic or ischaemic lesions sustained in the perinatal period.

Figure 3  Girl (case 13) examined eight days after birth (cranial ultrasound scan): midcoronal view (7.5 MHz) showing increased echogenicity in the left basal ganglia region.

arteries. Twelve infants were over 1 year of age at the time of writing. Seven (four with infarction, one with basal ganglia lesions, and one with haemorrhagic lesions) were normal at follow up. Three infants with middle cerebral artery infarcts have a hemiplegia, which is mild in two and moderate in one. One infant who had haemorrhagic venous infarct had a mild asymmetry of tone. The infant with normal imaging had abnormal movements and persistent seizures for which no cause has yet been found.

At the time of writing, three infants are between 6 and 12 months; one, with normal MRI, is normal. Two had an infarct, one shows mild hemiplegia, and the other mild tone abnormalities. Details are shown in table 3.

Figure 4  Girl (case 13). Inversion recovery sequences (IR 3800/30/930) (A) and (B) and (IR 3400/30/800) (C). Aged 8 days, a region of high signal intensity is seen in the left lentiform nucleus (A). At 2 weeks of age a cystic low signal region is seen in the left lentiform nucleus (B). At 5 months of age a small cystic lesion is seen. The left lateral ventricle is mildly dilated and less myelin is seen in the left frontal lobe (C).
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Figure 5  Boy (case 14) examined five days after birth (cranial ultrasound scan): coronal scan (7.5 MHz) showing bilateral increased echogenicity in the periventricular white matter, more pronounced on the left and suggestive of haemorrhage.

without evidence of HIE, our results highlight the frequency with which clinically important lesions are found and hence the importance of investigating all infants presenting with seizures irrespective of the clinical history or the presence of other clinical neurological signs. Serial ultrasound scans detected the lesions in 12 infants by the end of the first week, suggesting cerebral infarction in nine out of the 10 in whom this lesion was diagnosed on MRI, and also correctly identifying basal ganglia haemorrhagic/ischaemic lesions and parasagittal lesions. MRI not only identified lesions in two additional infants (n=14), but also provided much better anatomical definition of the extent of the lesions. Similar results have been found in a recent study which also described ultrasound scans and MRI findings in a cohort of infants with neonatal seizures. Although in this study subjects with seizure due to hypoxic-ischaemic encephalopathy or other known causes were also included, and cerebral lesions, such as focal ischaemic lesions, diffuse brain oedema, and venous infarction in eight of the nine infants in whom there was no identifiable clinical cause for the seizures, were still found. However, Rollins et al found it difficult to evaluate when the insults occurred in their cohort. This could be partly due to the fact that images were...
performed late, 12 out of 15 MRI being performed after 1 week of age, and only one had sequential MRI in the neonatal period.

Our results also clearly indicate that both early and repeated imaging are necessary not only to identify different patterns of lesions but also the timing of the insult. Early imaging permitted the identification of cerebral changes which normalised or became less obvious in the first weeks of life. This was shown in three children with haemorrhagic lesions in whom, at 3 weeks of age, these could no longer be detected and in one infant with infarction in whom only widening of the sulci could be observed after six months. However, a normal early ultrasound scan in the first days of life did not preclude the presence of lesions and early subtle abnormalities can be difficult to detect. The initial ultrasound scans were abnormal in the infants with haemorrhagic lesions but were less reliable in detecting infarction as six out of 10 infants had no signs on early ultrasound scan. MRI was better than ultrasound scan, as conventional MRI showed the infarction in six out of eight infants who had a scan in the first five days. The lesions became apparent on both ultrasound scan and MRI during the first week. This suggests a perinatal onset, supported by the findings of the diffusion weighted imaging. Diffusion weighted imaging identified on the initial scan all the ischaemic lesions.

The value of this technique has recently been described in infants with cerebral infarction and HIE. Brain lesions can be detected by this method in the first days of life, when they are less well seen with conventional MRI imaging. Diffusion weighted images become less abnormal towards the end of the first week, by which time ischaemic lesions can be more easily seen on conventional imaging. Studies in animal models have shown that the changes on diffusion weighted imaging are seen within a few minutes or hours after the injury and become less pronounced during the evolution of the lesion. The timing of events in animals would suggest that in our cohort ischaemic lesions were sustained in the perinatal period, despite the absence of fetal distress. Our findings cannot exclude an early postnatal onset but make it very unlikely that these lesions antedate delivery by several days, thus allowing for recovery and a normal Apgar score.

In conclusion, our data highlight the importance of early and serial imaging in all the infants with neonatal seizures. Cranial ultrasound scanning, when performed soon after the onset of the seizures and repeated at the end of the first week, will identify the presence of a lesion in most of these infants. Because of the ease of its applicability, ultrasonography is valuable for identifying the presence of lesions. However, early and serial MRI examinations will help not only to detect lesions, such as posterior infarcts which are easily missed on ultrasound scan, but will also give a better anatomical definition of the extent of the lesion, more information on the type of lesions, and will indicate the presence of other changes not seen on ultrasound scan. Having an early definite diagnosis in neonatal seizures with clear anatomical definition is of great help with clinical management, prognosis, and generally helps to alleviate parental distress. The combined use of these methods and the introduction of new MRI techniques, such as diffusion weighted imaging and, possibly, MRI angiography, offers significant progress in the diagnosis, and in timing the occurrence, of these lesions and may help lead to a better understanding of their aetiology.

Eugenio Mercuri is supported by a grant from the University of Messina, Italy. Mary Rutherford is supported by the Spastics Society. Jacqueline Pennock is supported by the Medical Research Council. Frances Cowan is supported by the Leverhulme trust.