Diagnosis of neonatal seizure by continuous recording and rapid analysis of the electroencephalogram

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SUMMARY Clinical diagnosis of neonatal seizure is difficult and repeated seizures may be unrecognised. To assist in early diagnosis we recorded continuously the electroencephalogram (EEG) of very sick newborns while intensive care continued. In 25 babies at high risk of seizure a continuous record of two channels of EEG, ECG, and respiration was made for periods varying from 11 hours to 16 days. The method employed produced an EEG largely free of movement and electrical artefact which was analysed rapidly using a visual display unit. Electroencephalographic seizure activity was recorded in 20 babies, and continuous monitoring of the EEG allowed earlier recognition of seizure than was possible with clinical observation.

Seizures during the neonatal period are a considerable problem, not only because they are a symptom of neurologic or metabolic disorder, but because there is a strong association between seizure and permanent handicap in the survivors. Recent studies in animals by Wasterlain *et al.* suggest that the poor prognosis may not be a consequence solely of the underlying illness, but that the neonatal brain is susceptible to permanent damage as a consequence of the seizures.^{1–6}

Watanabe, in a study of 215 newborns with clinical signs of seizure confirmed by electroencephalogram (EEG), found that 11.3% had atypical or subtle physical signs. He described the presence of subclinical seizures but did not give an incidence.⁷ Rose and Lombroso also found that 19 of 137 babies (14%) with EEG evidence of seizures had very few accompanying clinical signs.⁸ Electroencephalographic seizure activity has been reported in newborns who were paralysed to facilitate artificial ventilation.^{9,10} The diagnosis of seizure in the newborn is therefore difficult, and repeated seizures may be unrecognised.

The reported incidence of seizures in the newborn varies from 1.5–14.0/1000 live births.^{11–16} This may be the result of differences in the population at risk and in perinatal care, but it may also reflect the difficulty in making an accurate clinical diagnosis of seizure. In babies who are admitted to an intensive care nursery the incidence is as high as 3%.¹⁷

The high incidence of seizures, the difficulty in making a diagnosis, and the increasing use of paralysis to facilitate artificial ventilation indicate a

need to monitor continuously the EEG of very sick babies receiving intensive care. There are major problems associated with making a prolonged record of a standard EEG. Firstly, the record is subject to artefact during the babies' spontaneous movements and during nursing and medical procedures; secondly, electrical interference poses appreciable difficulties; and finally, the recorder is large and may obstruct access to the baby. We aimed to assess a new method of making a continuous record of the EEG in very sick babies receiving intensive care and to evaluate the usefulness of these records in the diagnosis of seizure.

Patients

Twenty five babies who were considered to be at high risk of seizure because of perinatal complications were studied. The clinical details are summarised in the Table. Their birthweights ranged from 790–4160 g, and their gestational ages at the time of the record ranged from 26–41 weeks.

Methods

A small battery powered four channel tape recorder which measured 112×86×36 mm was used to record two channels of EEG, one channel of ECG, and on the fourth channel a time signal and an event mark or else transthoracic impedance. (Medilog 4–24 Recorder and HDX-82 Preamplifiers, Oxford Medical Systems). The tape speed allowed 24 hours

Table Clinical details and EEG findings

Sex	Gestation (wks)	Birthweight (g)	Risk factor	Age at onset of record (hrs)	Total recording period (hrs)	Total seizures		Maximum seizures in 24 hours		Anticonvulsant treatment	Clinical signs
						Number	Duration (hrs)	Number	Duration (hrs)		
F	41	3995	Birth asphyxia	6	384	667	25-9	186	9-2	Phenobarbitone	Clonic movements
M	41	3400	Birth asphyxia	4	336	650	39-0	155	4-5	Phenobarbitone	No signs
M	41	2930	Birth asphyxia	24	48	414	11-5	241	6-0	Phenobarbitone	Paralysed
F	40	3230	Birth asphyxia	6	261	381	20-6	93	5-5	Thiopentone	No signs
M	38	2590	Metabolic acidosis	12	72	241	20-4	99	10-3	Diazepam, phenobarbitone, phenytoin, paraldehyde	Clonic movements
M	38	2840	Birth asphyxia	4	144	235	7-3	186	6-0	Phenobarbitone, phenytoin, paraldehyde	Clonic movements
M	34	2930	Birth asphyxia	2	11	200	3-7	200	3-7	Phenobarbitone, phenytoin, paraldehyde	No signs
M	32	2750	<i>Escherichia coli</i> meningitis	8	32	192	10-6	192	10-6	Phenobarbitone, paraldehyde, diazepam	Clonic movements
M	27	1190	Perinatal asphyxia	3	120	188	8-1	91	3-6	Phenobarbitone, phenytoin, paraldehyde	Paralysed
M	26	1200	Hyaline membrane disease, hypoxia, intraventricular haemorrhage	30	72	147	4-7	83	2-6	Phenobarbitone, phenytoin, paraldehyde	Paralysed
M	40	4160	Temporal lobe haematoma, intraventricular bleed	10	24	100	5-0	100	5-0	Phenobarbitone, paraldehyde, phenytoin	Clonic movements, opisthotonic posturing
F	24	790	Cardiac arrest with asphyxia	6 weeks	24	76	1-3	76	1-3	Phenobarbitone, diazepam	No signs
F	41	3130	Birth asphyxia	6	168	55	4-3	49	3-8	Phenobarbitone, phenytoin, paraldehyde	Opisthotonic posturing, apnoea
M	42	4160	Birth asphyxia	11	120	45	5-0	44	4-8	Phenobarbitone, phenytoin	L-sided clonic movements
F	40	3390	Birth asphyxia	5	48	13	1-3	13	1-3	Phenobarbitone	Opisthotonic posturing
F	40	3460	Birth asphyxia	6	192	10	0-75	8	0-3	Phenobarbitone	Opisthotonic posturing
M	33	1940	Hyaline membrane disease, birth asphyxia	6	120	2	0-1	2	0-1	No treatment	No signs
M	38	2550	Birth asphyxia	12	72	1	0-06	1	0-06	Phenobarbitone	Clonic movements
M	40	3800	Birth asphyxia, meconium aspiration, persistent fetal circulation	4 days	48	1	0-03	1	0-03	No treatment	Paralysed
F	38	2530	Birth asphyxia	12	24	1	0-18	1	0-18	Phenobarbitone	Opisthotonic posturing
F	41	3880	Birth asphyxia	10	24	0	—	—	—	—	Opisthotonic posturing
M	32	1840	Birth asphyxia	18	48	0	—	—	—	—	Clonic movements
F	27	1020	Hyaline membrane disease, birth asphyxia	12 days	48	0	—	—	—	—	Unconscious
M	26	810	Birth asphyxia	4	120	0	—	—	—	—	Tonic posturing
F	38	2725	β -haemolytic septicaemia	8	120	0	—	—	—	—	Paralysed

of record to be stored on a conventional 120 minute cassette tape (TDK AD-C 120, TDK Electronic).

The EEG was recorded using silver/silver chloride cup electrodes filled with saline jelly. These were fixed to the scalp with collodion and the holes in the electrode were sealed with collodion to prevent evaporation of the conducting gel (Fig. 1). The skin/electrode impedance was measured at 6–8 hourly intervals and kept below 5 K ohm. When necessary the collodion seal was dissolved with acetone and additional conducting jelly was injected. The hole was then resealed with collodion. The EEG record was bipolar between F_3-P_3 and F_4-P_4 with an indifferent electrode placed on the scalp. The filter band width was set at 0.5–100 Hz.

The transthoracic impedance was measured using silver/silver chloride cup EEG electrodes filled with saline jelly attached to the chest with collodion and the ECG was recorded from silver/silver chloride disposable electrodes.

The tape record was reviewed at intervals determined by the clinical condition of the baby and by the previous findings. The tape was replayed on a visual display unit (PMD 12 Virgo Special, Oxford Medical Systems) that automatically presented the

recorded signal as 'pages' of data comprising 8 or 16 seconds of EEG, ECG, and thoracic impedance record. The 'pages' were presented at a 20th or a 60th of the real time; in the latter case allowing rapid visual scanning of 24 hours of data in 24 minutes. Sections of the record showing abnormality could then be reviewed at a manually operated speed. During the recording, a bedside monitor (Oxford Medical Systems) was used to display simultaneously the EEG, the ECG, the heart rate, the chest wall movement and, in those babies with intra-arterial catheters, the blood pressure wave form.

A standard definition of an electroencephalographic seizure discharge was used. This was an orderly build up and termination of rhythmic sharp and slow waves, where the discharge persisted for longer than 20 seconds (Fig. 2), or the sudden onset and termination of repetitive and rhythmic waves of a single frequency in the 4–13 Hz range (Fig. 3) when the discharge persisted for longer than 20 seconds.¹⁸

In a preliminary study in which a standard EEG recorder was used, we found that if the electrodes alone were fixed to the skin then artefact resulting from movement was an appreciable problem. This

Fig. 1 Attachment of electrodes and preamplifiers to the scalp with collodion.

Fig. 2 Seizure discharge with abrupt onset of synchronous and symmetrical rhythmic sharp and slow waves in the right and left channel of the EEG.

Fig. 3 Seizure discharge of rhythmical waves in the θ frequency in the right channel of the EEG.

artefact occurred in both the EEG and the transthoracic impedance record, and it obscured long sections of the record (Fig. 4). To reduce movement artefact in the EEG record the electrodes were placed at the F_3-P_3 and F_4-P_4 positions where they would not be in contact with the mattress. To protect the electrodes from displacement during movement, the miniaturised preamplifiers ($13 \times 13 \times 6$ mm) were also fixed to the scalp with collodion. Thus displacement during movement occurred at the scalp/preamplifier junction and not at the EEG electrode (Fig. 1). To minimise displacement of the electrodes used to record transthoracic impedance, the patient leads were fixed to the chest wall using adhesive tape and collodion. During application of the electrodes the clinical condition of the baby, the heart rate, and the blood pressure were carefully observed for adverse changes.

Results

The application of the electrodes took approximately 30 minutes and did not disturb the clinical condition of any of the babies. Recording did not interfere with intensive care; nursing and medical procedures could continue; and the tape recorder remained connected during all investigations and

Fig. 4 Movement artefact in a standard 9 channel EEG record compared with an artefact free simultaneously recorded 2 channel EEG from electrodes and preamplifiers attached to the scalp with collodion.

could be transported with the baby if necessary. Access to the anterior fontanelle was preserved to allow regular ultrasound scanning of the brain, and most of the scalp remained available for intravenous cannulae (Fig. 1). Only after 5–6 days did the electrodes need refixing to the scalp. The only complication from the procedure was a localised allergic skin reaction to collodion in one baby; this subsequently resolved completely.

The recording period varied between 11 hours–16 days; the median was 72 hours and a total time was 2680 hours (Table). During prolonged records approximately 30 minutes of attention per day was necessary to maintain a satisfactory skin/electrode impedance. The time taken to analyse a 24 hour record varied from 30 minutes when no abnormality was found to three hours for a more complicated record showing EEG abnormalities. Movement artefact was reduced to no more than 10% of any one tape, and there was no electrical interference on the records, despite the complex electrical environment in the intensive care nursery—presumably because of the short distance between the electrodes and the preamplifier.

Electroencephalographic seizure activity was recorded in 20 of 25 babies studied (see Table). In 11 babies clinical signs accompanied some but

not all of the seizures. Four babies were paralysed during the seizure activity, and in five there were no associated clinical signs. For 14 babies the seizure activity was confined to paroxysmal discharges of rhythmic sharp or slow waves (Fig. 2), in five both paroxysms of rhythmic sharp or slow waves and paroxysmal discharges of rhythmical activity in the α or θ frequency were found (Fig. 3), and in one baby the seizure activity consisted solely of paroxysmal discharges of rhythmical activity in the α or θ frequency. The electroencephalographic seizure activity seen in the babies without clinical signs of seizure was not different from that seen in babies with accompanying signs.

A total of 3619 episodes of electroencephalographic seizure activity were recorded (Table); 2279 (63%) occurred synchronously and symmetrically in both the right and left channels, 108 (3%) occurred simultaneously but asynchronously in the right and left channel, while 1232 (34%) were recorded in only the right or left channel. Eighty two per cent of the seizure discharges comprised paroxysms of rhythmic sharp and slow waves, and 18% of paroxysms of rhythmical activity in the α or θ frequencies. Metabolic abnormalities accompanied the perinatal complications and seizures in 15 babies, but electroencephalographic seizures continued despite correction of these disorders. Seizure activity stopped within 6 hours of giving anticonvulsant drugs in only 4 babies, although serum values were within the accepted therapeutic range in all babies.

Discussion

The pathogenesis of brain damage as a consequence of repeated seizures has been attributed to neuronal necrosis secondary to increased neuronal energy requirement in the presence of the hypoxaemia that may accompany the motor activity of a seizure.¹⁹ In his studies in animals, however, Wasterlain found that seizures during the neonatal period (induced by indirect electroconvulsive shock, flurothyl, bicuculline, or fever) inhibit brain DNA synthesis, permanently reduce the number of brain cells and the brain size, and delay behavioural milestones even in animals paralysed and adequately ventilated and oxygenated throughout the seizure. Similar effects have not been found in studies of mature animals.¹⁻⁶

These studies in animals suggest that the newborn may be particularly susceptible to adverse neurological consequences from repeated uncontrolled seizures. The American National collaborative perinatal project²⁰ found that cerebral palsy and mental retardation were strongly related to the duration of the longest seizure and the number of

days in which repeated seizure occurred in the neonatal period. Plum, Posner, and Troy,²¹ in studies of dogs and primates, reported a loss of cerebral blood flow autoregulation, a rise in mean arterial blood pressure, and a consequent rise of 200% in cerebral blood flow during seizures. Lou and Friis-Hansen²² reported an increase in the mean arterial blood pressure of up to 40 mm Hg, and Perlman and Volpe²³ found increased cerebral blood flow velocity in the neonates during seizures with minimal motor activity. In view of the possible disturbances of autoregulation of cerebral blood flow in ill newborns, an abrupt increase in cerebral blood flow and intracranial pressure may accompany seizures and contribute to the pathogenesis of intraventricular haemorrhage.²⁴ These data also suggest that prompt control of electroencephalographic seizure activity may improve prognosis.

A review of the published reports on neonatal convulsions shows that most neonatal seizures occur within three days after birth, and that the percentage of seizures during this time varies from 43% as found by Brown, Cockburn, and Forfar to 86% as found by Burke.^{12 15 16 25 26} A continuous record of the EEG in ill babies during the first three days after birth will therefore identify most babies who have neonatal seizures.

The continuous record of the EEG enabled quantification of both the number of episodes and the total duration of electroencephalographic seizure activity during an acute neurological illness. With this method it is possible, for the first time, to relate the total duration of electroencephalographic seizure activity and abnormal interictal activity to the eventual outcome.

The continuous record also allows an assessment of the change in frequency of seizure activity over time and in response to treatment. While the aim of this study was not to assess the efficacy of treatment of seizure disorders, the unexpectedly high numbers of seizures, despite apparently adequate serum values of anticonvulsant drugs, suggests that antiseizure treatment did not alter the frequency of seizure activity in these babies.

The method of continuously recording the EEG does have limitations. Without the constant presence of a technician the recognition of the clinical signs of seizure will depend on intermittent nursing and medical observations, and subtle signs may be overlooked. Two channels of EEG may not show all focal discharges and the localisation of their origin will continue to require a standard 12-16 channel EEG. These disadvantages are balanced by a reduction in disturbance to the baby and minimal interference with nursing care. In addition, access is

maintained to the anterior fontanelle for ultrasound studies and to scalp vessels for venous or arterial cannulation.

The ability to diagnose seizure in those babies who are paralysed and in those with minimal motor signs of seizure depends upon the electroencephalographic finding of seizure activity. We describe a practical non-invasive method to monitor continuously the EEG in sick newborn babies.

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