Am. J. END Technol.
45:12–35, 2005
© ASET, Missouri

Review of Neonatal EEG

Aatif M. Husain, M.D.

Department of Medicine (Neurology)
Duke University Medical Center
Neurodiagnostic Center,
Veterans Affairs Medical Center
Durham, NC

ABSTRACT. *Neonatal electroencephalography (EEG) presents some of the most difficult challenges in EEG interpretation. It differs significantly in many ways from EEG of older children and adults. Technologically, acquisition of a neonatal EEG is significantly more difficult and different than an adult EEG. There are numerous features that are age-specific and change almost week-to-week in the preterm infant. Some features may be normal at one age and abnormal if they persist for several weeks. Many of these features also have different implications in neonates as compared to older individuals. These issues mandate a different approach to neonatal EEG interpretation. In this article an overview of neonatal EEG is presented. After a brief discussion of relevant technical issues, various normal EEG features encountered in neonates are discussed. This is followed by a discussion of the ontogeny of EEG, starting from the age of viability to the first few months of life. A description of various abnormalities follows. Finally, an approach to analysis of a neonatal EEG is presented.*

KEY WORDS. *Active sleep, delta brush, conceptional age, EEG, neonate, premature, quiet sleep.*

TECHNICAL CONSIDERATIONS

Neonatal EEG recordings present numerous challenges that make them technically difficult studies. Many recordings are done in the neonatal intensive care unit; consequently the technologist has to contend with a hostile environment. The patient's inability to cooperate, small head size, and fragile nature make

Received for publication: November 8, 2004.

Table 1. *A typical montage used in neonatal EEG recording.*

Fp1-C3
C3-O1
Fp2-C4
C4-O2
Fp1-T3
T3-O1
Fp2-T4
T4-O2
T3-Cz
Cz-T4
ECG
Chin EMG
LOC
ROC
Resp Effort

Legend: ECG = electrocardiogram, EMG = electromyogram, LOC = left outer canthus, ROC = right outer canthus, Resp = respiratory

electrode application and running the test difficult. Some unique considerations in the technical aspects of performing a neonatal EEG are discussed in this section.

Electrodes

A neonatal EEG should have a minimum of 16 channels per criteria established by the American Clinical Neurophysiology Society (ACNS 1994a). Since EEG alone is often inadequate in resolving the behavioral state of the neonate, other polygraphic data should be monitored. These polygraphic variables include electrocardiogram (ECG), electromyogram (EMG), extraoculogram (EOG), and respirations. These will be discussed in more detail below.

Though scalp EEG electrodes can be applied using the 10–20 System of electrode placement, often a reduced number of electrodes are used. The reduced array of electrodes is especially appropriate for premature neonates with very small heads. Fewer electrodes allow greater interelectrode distance making recording brain activity easier and the chance of creating salt bridges less. Common electrode sites include C3-C4, T3-T4, O1-O2, and Cz. Additionally, Fp1-Fp2 or F3-F4 and bilateral ear (A1-A2) or mastoid (M1-M2) electrodes are applied (Stockard-Pope et al. 1992a). A commonly used montage is presented in Table 1. The use of a single montage throughout the entire tracing is appropriate for a neonatal EEG (ACNS 1994a).

As noted above, several noncerebral polygraphic electrodes should also be applied. ECG electrodes are commonly applied to the left and right arms. They allow recording of pulse and ballistocardiographic artifacts. Submental EMG is monitored by placing two electrodes on the left and right sides of the inferior aspects of the

Table 2. *Neonatal EEG amplifier settings.*

Channel	LFF (Hz)	HFF (Hz)	Sensitivity
EEG	0.3–1	70	7 μV/mm
EOG	1	70	7 μV/mm
EMG	5	70	3 μV/mm
ECG	5	70	Variable
Resp Monitor	0.3	15	Variable

Legend: EEG = electroencephalogram, EOG = electro-oculogram, EMG = electromyogram, ECG = electrocardiogram, Resp = respiratory, LFF = low frequency filter, HFF = high frequency filter

mandible. This channel is helpful in detecting movement and also monitoring EMG activity during various behavioral stages. EOG electrodes are applied above the left and below the right outer canthi. These are referenced to contralateral A1-A2 or M1-M2. With this electrode placement, eye movements in any direction will register as out-of-phase deflections in the eye leads. This is especially helpful in active sleep. Respirations can be monitored in one or more channels. Commonly a piezoelectric transducer is placed around the chest or abdomen to monitor respiratory movements. Nasal and/or oral thermisters can also be used when additional respiratory monitoring is needed, i.e. in patients being evaluated for apneic spells. The sensitivity and filter settings for the various channels are presented in Table 2. Electrode impedances should be kept below 5000 ohms (ACNS 1994a).

Recording Time

Neonatal EEG should be recorded for a longer period than the routine adult tracing. It is ideal if the neonate cycles through wakefulness, active sleep, and quiet sleep during the tracing. Since typically a neonate takes 50 to 60 minutes to cycle through all three stages, a neonatal EEG should be run for at least 60 minutes. If possible, the EEG should be scheduled near the feeding time of the neonate. Electrodes should be applied during feeding. Soon after feeding the neonate can be expected to fall asleep, thus providing an opportunity to record active and quiet sleep. Towards the end of the tracing the neonate should be awakened to determine background during wakefulness and reactivity. Photic stimulation is rarely used.

Notations

Technical notes are very important in neonatal EEG. In addition to the chronological age (time since birth), the neonate's gestational age (time between mother's last menstrual period and birth), and conceptional age (gestational age plus chronological age) should be noted. It is the conceptional age that should be used in interpretation of the tracing. Medical status, medications, mechanical ventilation, scalp swelling, and other relevant observations should be noted. Notes regarding motor activity, eye movements, and respiration should be provided to the interpreter so that behavioral states can be recognized with greater confidence. Rhythmic movement should also be noted, and the technologist should try to restrain the involved limb to see if the activity can be stopped. The importance of technical notations during a neonatal EEG cannot be overstressed.

NEONATAL EEG PATTERNS

In neonatal EEG, various patterns are present at different stages of development. Persistence of these patterns beyond their typical age range suggests dysmaturity, whereas their earlier appearance most often indicates a miscalculation of the child's gestational age. In this section features and common patterns of neonatal EEG are discussed.

Continuity

When EEG activity first appears, it is discontinuous containing periods of electrical activity, called bursts, separated by periods of inactivity, called interburst intervals. When the premature neonate reaches full term, the duration of the bursts increases, whereas the duration of the interburst intervals decreases. Eventually shortly after term, the bursts become continuous, and the EEG is continuous at that point. The duration of the interbursts intervals can be used to estimate the maturity of the neonate; however it should be noted that various pathological conditions may increase these intervals. At 24 weeks conceptional age, the mean interburst interval is about 10 seconds; this decreases to about 2 to 4 seconds at term (Benda et al. 1989, Clancy et al. 2003, Hayakawa et al. 2001).

Bilateral Synchrony

Bilateral synchrony refers to the appearance of similar EEG activity over homologous areas of the brain simultaneously. Synchrony is best measured during discontinuous parts of the tracing. When bursts of activity occur more than 1.5 seconds apart over homologous brain areas, they are said to be asynchronous. Infants less than 30 weeks of age exhibit virtually complete synchrony. However, by 31 to 32 weeks, only 70% of the bursts are synchronous; by 33 to 34 weeks 80% are synchronous, and by 37 weeks once again 100% of the bursts are synchronous (Lombroso 1985, Tharp 1990).

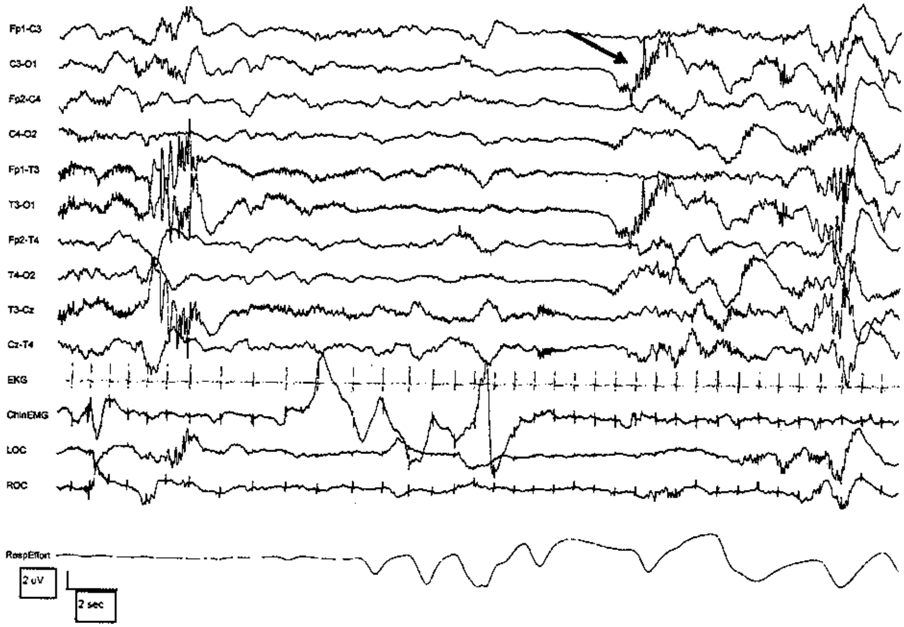

FIG. 1. EEG of a 32 week conceptional age neonate showing a trace discontinu pattern. Note the delta brushes (arrow).

Symmetry

Symmetry of an EEG tracing implies that the amplitude and frequency of homologous brain regions is comparable. Asymmetry should be judged over reasonably large segments of the tracing. Generally, amplitude asymmetry is considered significant if the difference is greater than a 2:1 ratio (Clancy et al. 2003).

Trace Discontinu

In the youngest premature neonates when EEG activity first appears, it is discontinuous and consists of bursts of high amplitude waveforms of mixed frequencies, maximal in the posterior head regions, separated by interburst intervals that have an amplitude of less than 25 μV. This activity is referred to as trace discontinu (Figure 1). The duration of the interburst intervals ranges from a few seconds to over 30 seconds, depending on conceptional age. Trace discontinu pattern is well developed by 32 weeks of conceptional age, and persists as the pattern of quiet sleep until 36 weeks (Dreyfus-Brisac 1970).

FIG. 2. EEG of a 40 week conceptional age neonate showing a trace alternant pattern of quiet sleep.

Trace Alternant

As the neonate's age increases, the amplitude of the interburst interval increases and its duration shortens. Once the amplitude reaches 25 μV, this activity is called trace alternant (Figure 2). This transition usually occurs between 34 to 36 weeks conceptional age. The activity in the interburst intervals consists of mixed frequencies with amplitudes between 25 to 50 μV. The duration of the bursts is usually 2 to 4 seconds by term. The bursts consist of delta frequency activity with superimposed faster frequencies and can have amplitudes as high as 300 μV. By full term, the trace alternant pattern begins to fade and gives way to more mature patterns (Ellingson and Peters 1980).

Continuous Slow Wave Sleep

As the interburst intervals of the trace alternant pattern shorten, the bursts develop high amplitude delta and theta activity. This activity eventually becomes continuous during quiet sleep and is called continuous slow wave sleep (Figure 3). Fragments of this activity start to appear by 36 weeks conceptional age, however it is at about 44

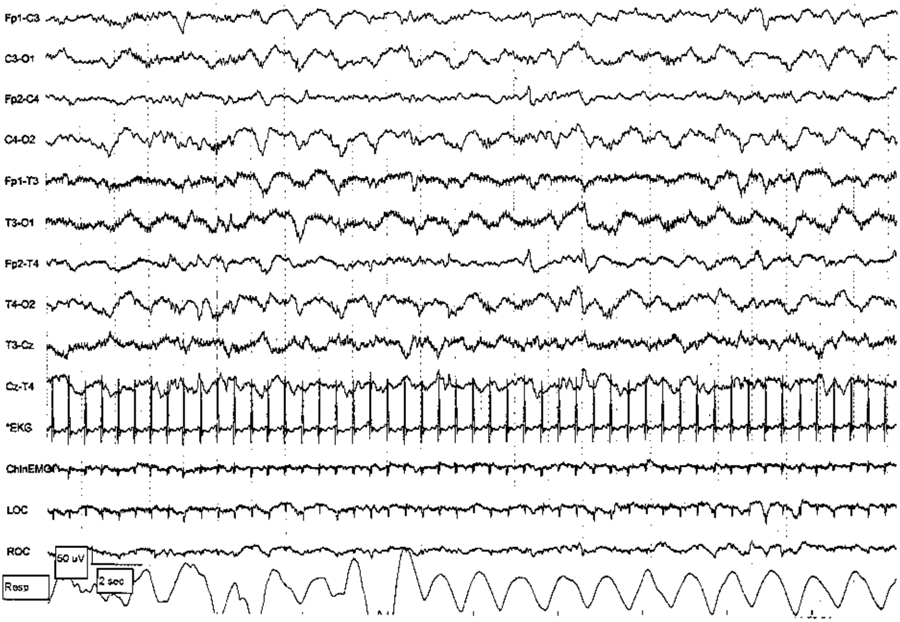

FIG. 3. EEG of a 41 week conceptional age neonate showing a continuous slow wave sleep pattern during quiet sleep.

to 45 weeks that this activity constitutes all of the background during quiet sleep (Wantanabe et al. 1974).

Activite Moyenne

Activite moyenne, also referred to as low voltage irregular pattern, is a continuous EEG pattern that consists of theta with intermixed delta activity that is lower in voltage compared to other activity seen at this age (i.e., continuous slow wave sleep) (Figures 4 and 5). This activity appears around 36 weeks conceptional age during wakefulness and active sleep.

Sleep Spindles

Between 44 to 49 weeks conceptional age, sleep spindles appear in quiet sleep. They consist of 12 to 14 Hz activity seen most prominently over the central head regions. Sleep spindles at this age last about 3 to 5 seconds and have a characteristic rectified (down slope is sharply contoured) morphology (Fisch 1991). Sleep spindles are asynchronous, but symmetric, at this age.

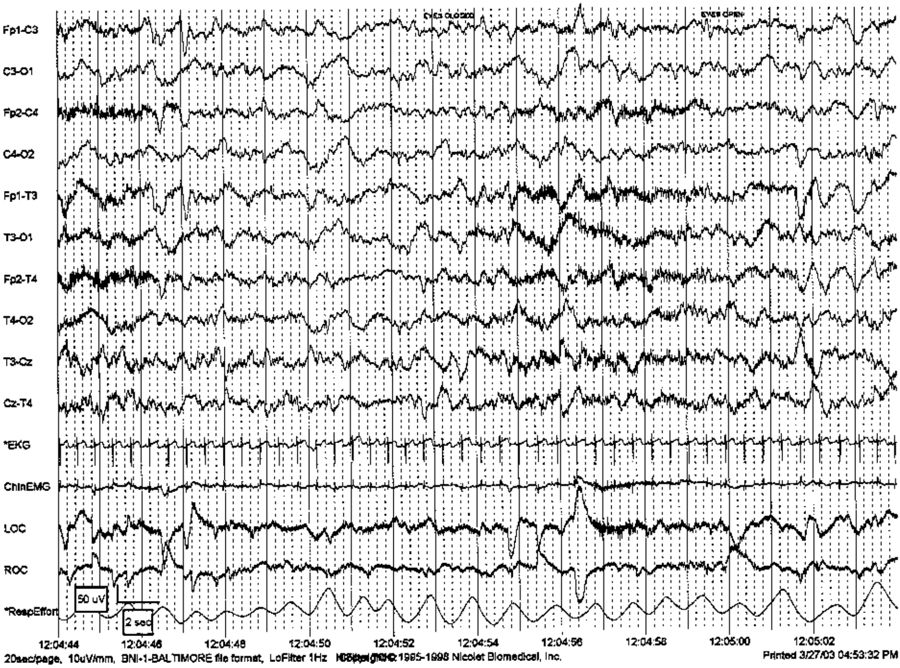

FIG. 4. EEG of a 37 week conceptional age neonate showing an activite moyenne pattern during wakefulness. Notice the rapid eye movements, EMG activity, and technologist's comments.

Delta Brushes

Delta brushes are also called "beta-delta complexes," "ripples of prematurity," "brushes," and numerous other names. They constitute the prime landmark of prematurity and are present between 29 to 38 weeks conceptional age. As their name implies, these complexes consist of an underlying 0.3 to 1.5 Hz delta waves of 50 to 250 μV amplitude with superimposed 8 to 20 Hz faster frequencies (Figure 1) (Dreyfus-Brisac 1968). These complexes first appear at 26 weeks in the central head regions. They increase over the next several weeks, and from 29 to 33 weeks they become a prominent feature during active sleep. During this time, the spatial distribution of delta brushes extends to the occipital and temporal regions. Beyond 33 weeks, delta brushes are present only in quiet sleep and mostly over the occipitotemporal regions. They are frequently asynchronous. By full term, delta brushes are rare and only seen in quiet sleep; they disappear completely by 48 weeks conceptional age (Hrachovy et al. 1990).

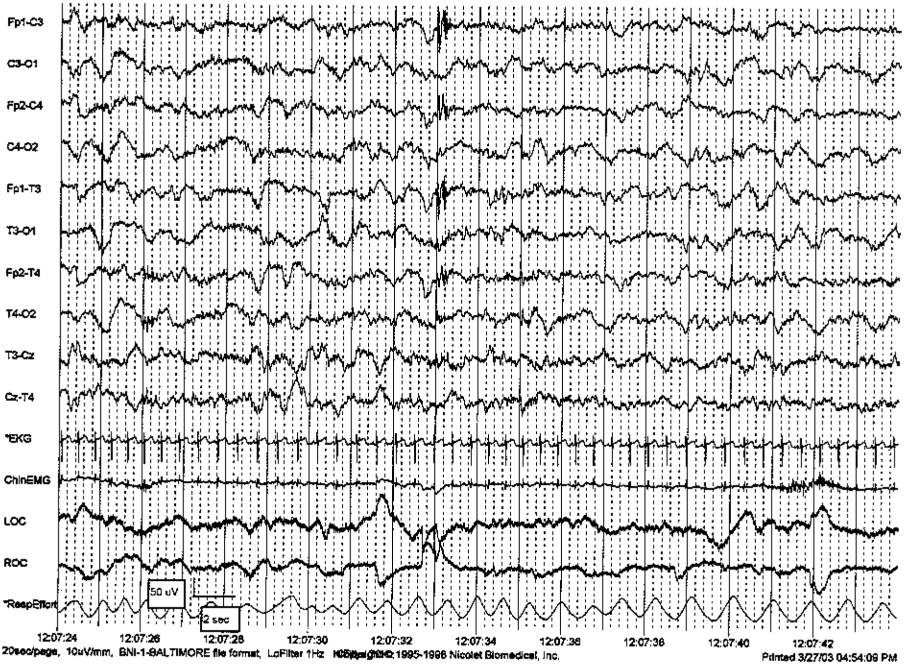

FIG. 5. EEG of a 37 week conceptional age neonate showing an activite moyenne pattern during active sleep. Notice the rapid eye movements and reduced EMG activity. This pattern is similar to the pattern seen during wakefulness in neonates of this age (i.e., Figure 4).

Monorhythmic Occipital Delta Activity

Monorhythmic occipital delta activity is 0.5 to 1 Hz monomorphic, high amplitude, surface positive delta activity which is seen in the occipital region as early as 23 to 24 weeks of conceptional age (Figure 6). It can last from 2 to 60 seconds. This activity is most prominent between 31 to 33 weeks and disappears by 35 weeks. Persistence beyond 35 weeks constitutes immaturity of the EEG. Monorhythmic occipital delta activity is frequently symmetric and synchronous, and forms the delta activity of delta brushes (Clancy et al. 2003).

Rhythmic Occipital Theta Activity

Rhythmic 4 Hz activity can occur in the occipital regions in premature neonates starting at the age of 23 weeks conceptional age. It occurs in runs of 2 to 10 seconds. It is most common by 30 weeks of age and begins to disappear by 33 weeks.

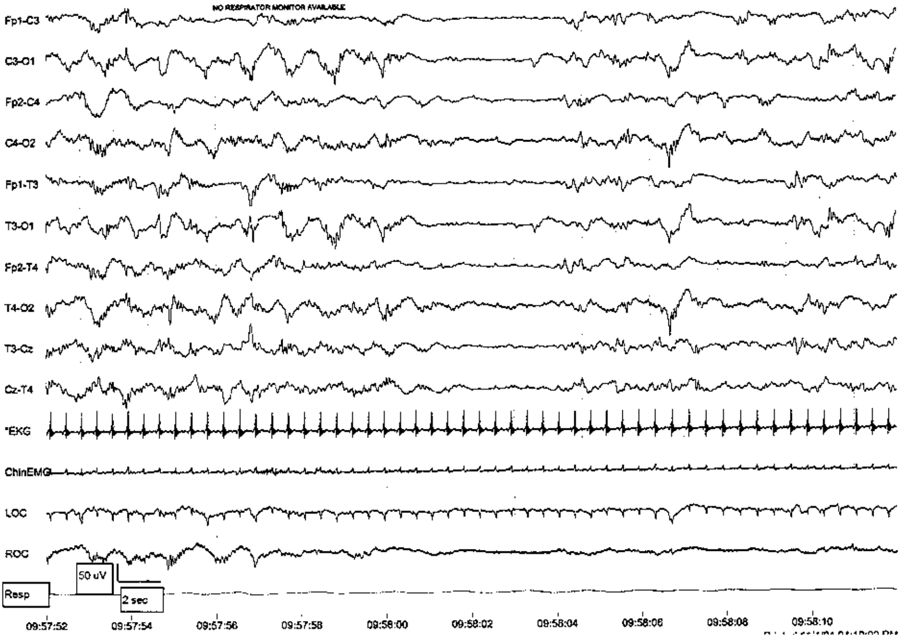

FIG. 6. EEG of a 33 week conceptional age neonate showing intermittent monorhythmic occipital delta during quiet sleep. A trace discontinu pattern is also present, a normal finding in this age group.

Rhythmic Temporal Theta Activity

At 26 weeks conceptional age, bursts of rhythmic 4 to 6 Hz temporal theta activity lasting less than 2 seconds can be seen in the midtemporal regions. They increase in persistence until 30 to 32 weeks when they are most frequent. Often this activity is sharply contoured, and hence is at times referred to as temporal saw-tooth waves. By 33 weeks, these rhythmic temporal bursts are often in the alpha frequency.

Centrotemporal Delta Activity

Centrotemporal delta activity occurs at a frequency of 0.5 to 2 Hz over the centrotemporal regions and serves as the foundation for delta brushes in this location. It is seen maximally at 30 weeks conceptional age and fades by 33 weeks (Clancy et al. 2003).

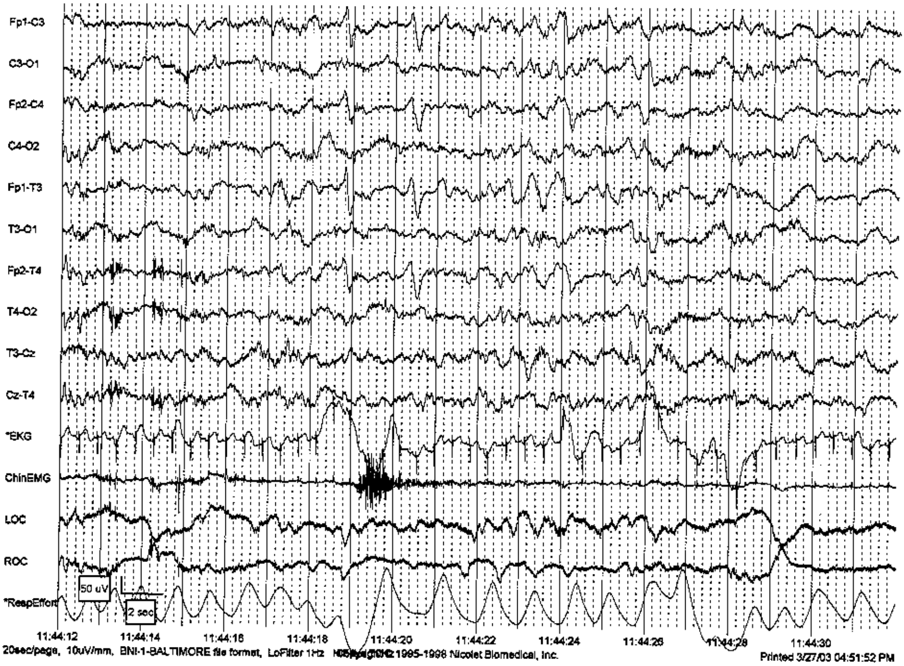

FIG. 7. EEG of a 37 week conceptional age neonate showing encoches frontales and anterior slow dysrhythmia during wakefulness.

Anterior Slow Dysrhythmia

Despite its name (*dys*rhythmia), anterior slow dysrhythmia is a normal pattern seen in premature infants. Anterior slow dysrhythmia consists of runs of delta activity in the anterior head regions that last a few seconds (Figure 7). This activity is symmetric and synchronous and may evolve somewhat in frequency and morphology, becoming more sharply contoured later in the run. It is seen in all behavioral states. Though this pattern is seen in normal neonatal EEG, various encephalopathies can increase the quantity of this pattern, thereby making it abnormal (Holmes and Lombroso 1993). Anterior slow dysrhythmia frequently occurs with frontal sharp waves known as encoches frontales, another normal feature in neonatal EEG.

Encoches Frontales

Encoches frontales are biphasic frontal sharp waves that frequently occur symmetrically and synchronously. Their initial component is a surface negative sharp wave that has an amplitude of 50 to 150 μV and a duration of about 200 msec. This is followed by a surface positive slower wave (Figure 7). Encoches frontales are maximally expressed at 35 weeks conceptional age; they are often present before this age, however are of low amplitude and infrequent. After 46 weeks they again become infrequent (Dreyfus-Brisac 1970). Encoches frontales frequently occur with anterior slow dysrhythmia. Though these sharp waves are not epileptogenic (suggestive of a lowered seizure threshold), their frequency increases in various types of encephalopathies. Frontal sharp waves that are symmetric and asynchronous may also suggest pathology (Clancy et al. 2003).

Focal Sharp Waves

Other than encoches frontales, focal sharp waves are not clearly understood. They can occur in any area of the brain but are most common in the temporal regions. Temporal sharp waves can occur in normal premature neonates, and they can signify significant pathology. Several features help differentiate between normal and pathological temporal sharp waves. The frequency of normal temporal sharp waves is about one per minute at 37 weeks of conceptional age and becomes even less frequent as the neonate reaches term. At 46 to 48 weeks, more than two to three temporal sharp waves per hour are abnormal (Clancy 1989). Normal temporal sharp waves also occur bilaterally, asynchronously, and either symmetrically or asymmetrically. Thus runs of sharp waves in one location are considered abnormal. Normal temporal sharp waves have an amplitude of less than 75 μV, duration of less than 100 msec, and a biphasic morphology. Sharp waves that are higher in amplitude, longer in duration, and have a complex polyspike morphology are abnormal. Temporal sharp waves are only seen during quiet sleep in a term neonate; if they are present during wakefulness they are more likely to be abnormal (Hrachovy et al. 1990, Lombroso 1985).

Central sharp waves can also occur in healthy premature neonates. They are usually of low voltage (less than 50 μV) and short in duration (less than 75 msec). Though they can persist until 41 weeks of conceptional age, they are uncommon after 37 weeks. Frontal sharp waves other than encoches frontales and occipital sharp waves are more likely to be pathological.

NEONATAL EEG ONTOGENY

As the fetal brain develops, the EEG patterns change in a predictable manner. EEG patterns can be so characteristic that estimation of the neonate's age is possible. Ontogeny of the EEG is thought to be the same regardless of whether the neonate is in utero or born prematurely. Thus the tracing should always be interpreted with reference to the conceptional age. The subsequent section reviews the typical features of the EEG at various age group, starting near the age of viability. For more details, other more comprehensive references should be consulted (Clancy et al. 2003, Goto et al. 1992, Stockard-Pope et al. 1992b).

Conceptional Age: Less Than 29 Weeks

At this age premature neonates show sparse behavior with rare body movements. Respirations are irregular and eye movements are rare. The EEG has a trace discontinu pattern with runs containing delta brushes, monorhythmic occipital delta activity, and occasional bursts of rhythmic occipital and temporal theta activity. The delta brushes are located over the central and occipital areas. The bursts of the trace discontinu pattern are typically synchronous, with over 90% occurring within 1.5 seconds of each other. The interburst intervals can be as long as 10 to 12 seconds, however become shorter as the neonate matures. The trace discontinu is monomorphic, not changing as the neonate behaviorally fluctuates between wakefulness and sleep. Thus, at this age, the EEG is not a reliable indicator of the behavior state of the neonate.

Conceptional Age: 30 to 32 Weeks

As the neonate matures, he has more body movements, occasional regular respirations, and rapid eye movements (REM). At this age wakefulness and active sleep may be differentiated electrographically from quiet sleep, however still much of sleep is still considered transitional (i.e., cannot be differentiated into active or quiet). During quiet sleep, trace discontinu is the predominant pattern with monorhythmic occipital delta activity and delta brushes in the bursts (Figure 1). The bursts of activity are less synchronous than previously, with only about 70% occurring within 1.5 seconds of each other. More frequent bursts of rhythmic temporal theta activity are present. During wakefulness and active sleep, the interburst intervals are considerably shorter, usually being less than 5 to 8 seconds. Increased movement may be seen in wakefulness, whereas in active sleep, REM and irregular respiration may be noted.

Conceptional Age: 33 to 34 Weeks

Active and quiet sleep can be more clearly differentiated at this age, however much of the recording still contains transitional sleep. During wakefulness and active sleep the interburst intervals are much shorter, with about 80% occurring synchronously. Frequent bursts of rhythmic temporal theta activity are noted, with gradual fading of monorhythmic occipital delta activity. Delta brushes are most prominent while the neonate is awake or in active sleep and are seen mostly in the central and temporal regions. Multifocal sharp waves also appear at this age, but are typically less than one per minute. The EEG also begins to demonstrate reactivity at this age.

Conceptional Age: 35 to 36 Weeks

Much of the tracing at this age can be assigned to either wakefulness, active sleep, or quiet sleep. The EEG is clearly reactive, usually diminishing in amplitude in response to stimulation, but rarely, an augmentation in activity can also be seen. During wakefulness and active sleep, the EEG becomes continuous, containing mixed frequency activity of low to moderate amplitude (activite moyenne) (Figures 4 and 5). Monorhythmic occipital delta activity and bursts of temporal theta activity disappear at this age (Figure 6). Active sleep is heralded by loss of EMG tone and frequent REM. Delta brushes are rarely seen in wakefulness and active sleep, but persist in quiet sleep. Activity in quiet sleep is still discontinuous, however the interburst intervals have an amplitude greater than 25 μV, and thus this activity is now called trace alternant. Approximately 85% of the bursts are synchronous between the two hemispheres. Encoches frontales and anterior slow dysrhythmia also appear at this age (Figure 7).

Conceptional Age: 37 to 40 Weeks

In healthy term neonates, behavioral states can be easily recognized electrographically, however still 25% of sleep is transitional. During wakefulness and active sleep either activite moyenne or a low voltage mixed frequency pattern with superimposed delta frequencies in the occipital region is seen. During quiet sleep, a trace alternant pattern is seen. If the neonate remains in quiet sleep for a sustained period, the trace alternant pattern gives way to a continuous slow wave sleep pattern (Figure 3). Delta brushes are still seen in quiet sleep. Encoches frontales and anterior slow dysrhythmia are also present, however multifocal sharp waves are less frequent (about two to three per hour at term).

Conceptional Age: 41 to 44 Weeks

The predominant activity during wakefulness and active sleep continues to be activite moyenne. During quiet sleep, the predominant activity is continuous slow wave sleep, except at the onset, at which point trace alternant may still be seen. The bursts of trace alternant are synchronous at this stage, and the interburst intervals are less than four seconds. Delta brushes and multifocal sharp waves disappear by 44 weeks conceptional age. At term, approximately 80% of sleep episodes begin with active sleep, which constitutes approximately 50% of total sleep time.

Conceptional Age: 44 to 48 Weeks

At this age, wakefulness and active sleep continue to have activity described above. Quiet sleep no longer has trace alternant, rather consists of continuous slow wave sleep. Sleep spindles appear at this age as well. They occur at a frequency of about 12 to 14 Hz and have a rectified morphology. They are best seen over the central head regions and are asynchronous. By 46 weeks, the majority of the sleep episodes begin with quiet sleep, which constitutes about 60% of total sleep time.

ABNORMALITIES

Severity of neonatal EEG abnormalities correlates with the severity of neurological insult to the neonate. This makes EEG in this age group a valuable tool in predicting outcome of at-risk neonates. Markedly abnormal and normal EEGs have the greatest reliability in predicting poor and good outcomes, respectively. Moderately abnormal EEGs do not correlate with subsequent psychomotor development. Serial EEGs are preferred to single recordings so that persistence of abnormalities can be determined. Single recordings with dysmaturity may have little significance, however if the pattern persists for several weeks, it may be more important prognostically. As an example, an EEG obtained soon after birth can show significant abnormalities due to stress of birth; these abnormalities may disappear completely within a few days and thus have little clinical significance. Neonatal EEG abnormalities can be divided into four categories: abnormalities of background activity, abnormalities of maturation, abnormal patterns, and neonatal seizures (Lombroso 1985, Stockard-Pope et al. 1992c).

Abnormalities of Background Activity

Electrocerebral Inactivity. As with other types of EEG, electrocerebral inactivity constitutes the most severe type of abnormality possible on neonatal EEG. In such an EEG, there is no cerebral activity greater than 2 μV. To interpret an EEG as demonstrating electrocerebral inactivity, the tracing must be obtained per criteria suggested by the American Clinical Neurophysiology Society (ACNS 1994b). According to these guidelines, the tracing must be obtained with a sensitivity setting of 2 μV/mm for at least 30 minutes. Due to the resilience of the neonatal brain, it is often recommended that a second EEG should be obtained several days later to rule out a transient disorder (Fisch 1991). Once hypothermia, sedative medications, hypotension, and electrolyte imbalances have been ruled out, electrocerebral inactivity is almost universally associated with a very poor outcome (Aso et al. 1989).

Burst-Suppression Pattern

A burst-suppression pattern is characterized by periods of excessively suppressed background (less than 5 μV) interrupted by bursts of abnormal activity. This pattern should not be confused with the normal discontinuous patterns of prematurity, trace discontinu and trace alternant. A burst-suppression pattern is not reactive to stimulation, and the interburst intervals often exceed 30 seconds. The bursts do not have any of the typical features seen with the normal premature patterns. In the burst-suppression pattern there is also absence of cycling between various behavioral states, making the EEG very monomorphic. The vast majority of neonates with this EEG pattern have a poor psychomotor prognosis (Tharp et al. 1989).

Low Voltage Pattern

A low voltage pattern in neonatal EEG is one in which the activity is 5 to15 μV during wakefulness and 10 to 25 μV during sleep (Monod et al. 1972). If this pattern persists for several weeks, it is associated with unfavorable outcome (Holmes et al. 1982).

Excessive Discontinuity

Excessive discontinuity is a term applied to neonatal EEG if the interburst intervals are longer than would be expected for the conceptional age. Maximum acceptable interburst intervals for neonates aged less than 30 weeks, 31 to 33 weeks, 34 to 36 weeks, and 37 to 40 weeks are 35, 20, 10, and 6 seconds, respectively (see Figure 8) (Hahn et al. 1989, Hayakawa et al. 2001). At term, an interburst interval of 30 seconds or greater is associated with poor neurological outcome (Menache et al. 2002). In such a pattern, the voltage of the suppressed activity and the activity present in the burst should be scrutinized. If the interburst activity is greater than 10 μV and the burst has normal activity, a favorable outcome is possible (Pezzani et al. 1986).

Depressed and Undifferentiated Background

With depressed and undifferentiated background, there is an absence of faster frequencies with a persistence of a slow background activity. There is also often a suppression of amplitude, and the tracing may be more discontinuous than what would be expected for conceptional age. This is a nonspecific pattern and can be seen with asphyxia, cerebral hemorrhage, cerebral dysgenesis, inborn errors of metabolism, etc. It has been associated with a poor prognosis (Monod et al. 1972).

Abnormal Asymmetry

Amplitude asymmetry between homologous areas of the brain that is consistently greater than 50% is considered abnormal (Aso et al. 1989, Lombroso 1985). The abnormality can be either excessively high or excessively low voltage, and it may be

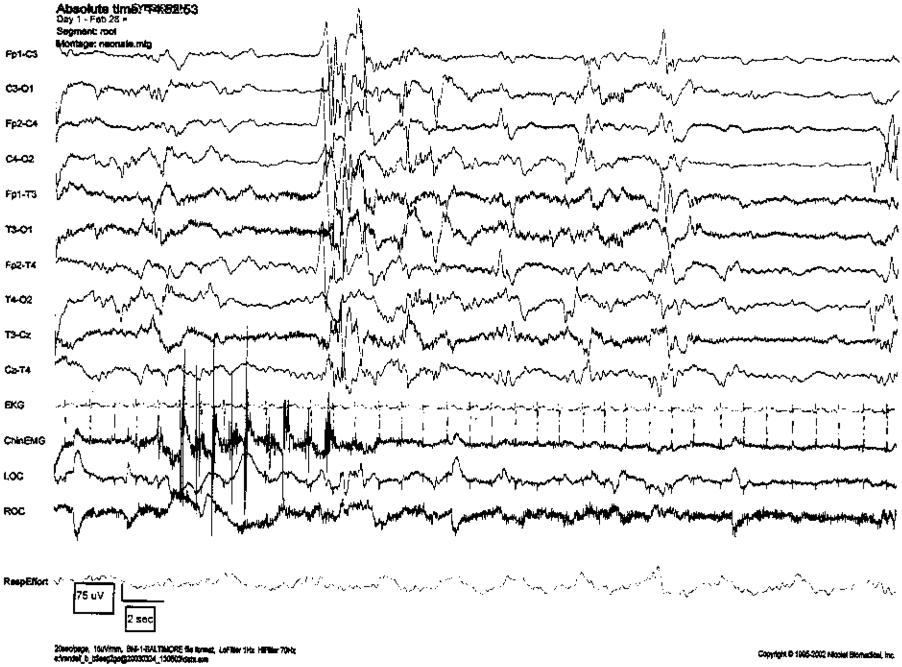

FIG. 8. EEG of a 39 week conceptional age neonate showing excessive discontinuity for age. The interburst activity is also of very low amplitude.

difficult to identify the side of abnormality. Presence of normal features of the background should be sought to help in determination of the normal side. Common causes of such focal amplitude asymmetry with simplification of underlying activity include stroke, venous or dural sinus thrombosis, contusion, hemorrhage, or abscess. These abnormalities are often associated with poor prognosis (Aso et al. 1993, Lombroso 1975). However, if there is only a depression of amplitude on one side with preservation of other normal background activity, a technical problem, such as electrode placement, scalp edema, or subdural fluid collection should be considered.

Abnormal Asynchrony

In EEGs of premature neonates, when interhemispheric bursts of activity occur within 1.5 to 2 seconds of each other, they are considered synchronous. Excessive asynchrony is when less than 25% of the bursts are synchronous (Stockard-Pope et al. 1992c). This degree of asynchrony is often associated with other abnormalities, such as excessive discontinuity or burst-suppression. Such an asynchronous pattern is seen with various acute conditions such as hypoxic-ischemic encephalopathy and meningitis, as well as chronic conditions such as periventricular leukomalacia and developmental abnormalities (i.e. agenesis of the corpus callosum) (Clancy et al. 2003). Abnormal asynchrony has been associated with poor outcome (Tharp et al. 1981).

Abnormalities of Maturation

If neonatal EEG patterns suggest a conceptional age at least two weeks younger than the actual conceptional age, the EEG is considered dysmature (Lombroso 1975). Such a pattern is usually seen in response to a chronic or subacute neurological or non-neurological illness. Because of the illness, these neonates experience a delay in brain maturation, which is reflected in the dysmature EEG pattern (Hayakawa et al. 1997). Persistent dysmaturity seen on serial examinations is associated with poor outcome.

The sleep-wake cycle of neonates may also be altered with various stressors. Absence of clear recognizable sleep-wake states by age 35 weeks conceptional age is an indicator of poor outcome (Pezzani et al. 1986). Increased amount of transitional sleep has also been reported with various medical and neurological illnesses (Wantanabe et al. 1980).

Abnormal Patterns

Positive rolandic sharp waves have, as their name implies, an initial surface positive component and are located in the central and vertex regions. They are rarely seen in otherwise healthy neonates younger than 32 weeks conceptional age, but are more frequently seen in older neonates and represent pathology (Blume and Dreyfus-Brisac 1982). Positive rolandic sharp waves usually have amplitudes between 50 to 250 µV and duration of less than 500 msec. They are most commonly associated with periventricular leukomalacia and intraventricular hemorrhage (Figure 9) (Novotny et al. 1987). These positive sharp waves are not very sensitive for these types of neurological complications, however are very specific (Clancy et al. 1984). It should be noted that these sharp waves do not suggest epileptogenicity. Positive sharp waves can also be seen in the temporal regions and are thought to have the same clinical significance as those in the central and vertex regions.

Multifocal sharp waves are considered normal, depending on their frequency and location, in certain age groups. However, if they occur with a frequency greater than expected for a particular age group or occur persistently in one location, they are regarded as abnormal (Figures 10 and 11). Frontal sharp waves (other than encoches frontales) and occipital sharp waves are always considered abnormal (Hrachovy et al. 1990). Most authors consider multifocal sharp waves a nonspecific finding suggestive of a neuronal insult. Unlike in adult EEG, these sharp waves are not

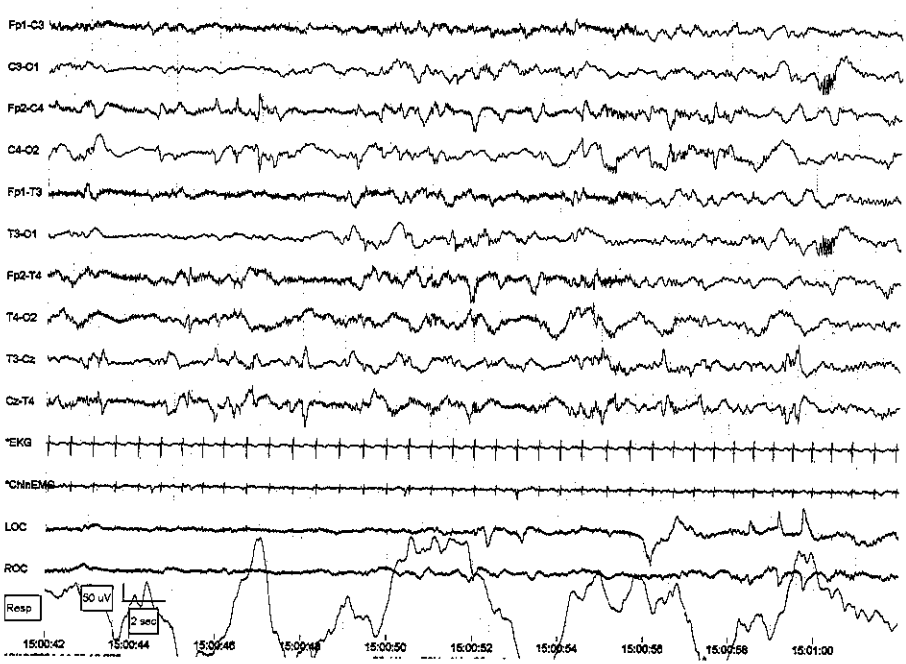

FIG. 9. EEG of a 39 week conceptional age neonate showing frequent positive spikes in the C4 and Cz area. This patient had severe intraventricular hemorrhage.

considered epileptiform and are not thought to represent a lowered seizure threshold (Hrachovy et al. 1990, Lombroso et al. 1985). Similarly, excessive amounts of anterior slow dysrhythmia is considered abnormal if it occurs excessively.

Neonatal Seizures

Neonatal seizures are difficult to diagnose clinically in premature and term neonates. Often paroxysmal clinical activity occurs that has no electrographic correlate, and at other times definite paroxysmal electrographic activity occurs that lacks clinical correlate. Video EEG monitoring studies have shown that a large number of neonatal seizures do not have a clinical correlate (Mirzrahi and Kellaway 1987, Scher et al. 1993). Like electrographic seizures in other age groups, neonatal seizures have a definite beginning, middle, and end with clear evolution. These features are important in differentiating ictal rhythmic discharges from artifacts (Figure 12).

The minimum duration for electrographic neonatal seizures has been set, somewhat arbitrarily, at 10 seconds. The majority of seizures in this age group

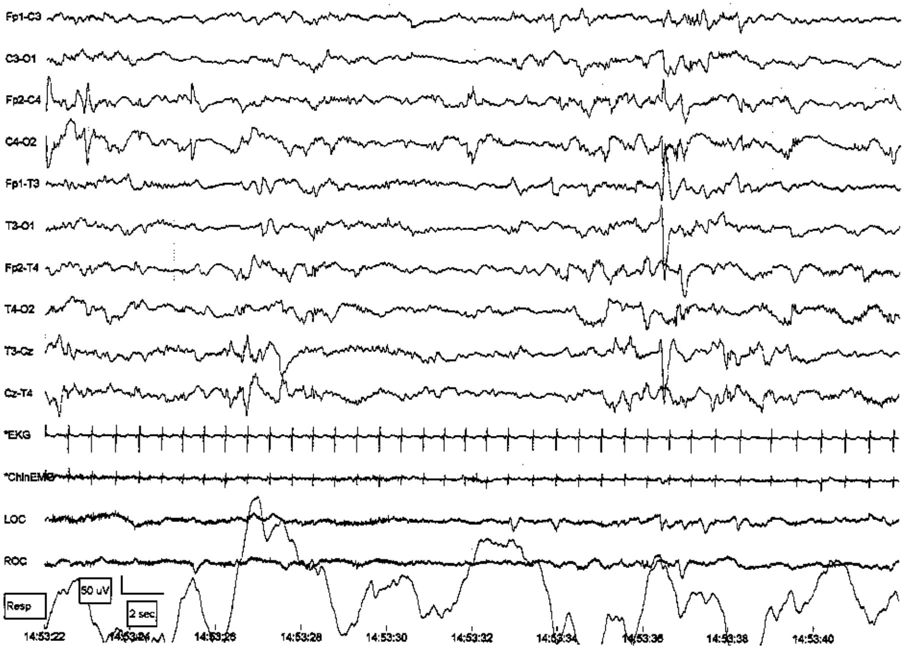

FIG. 10. EEG of a 40 week conceptional age neonate showing multiple areas of spike focus (C4 and T3). At other times in the tracing frequent spikes were also noted in the T4 region.

last less than two minutes (Clancy et al. 2003, Shewmon 1990). Ictal discharges lasting less than 10 seconds are called brief rhythmic discharges. Until recently, if these discharged occurred in isolation, without electrographic neonatal seizures, their significance was uncertain. However, there is growing evidence that these brief discharges may be associated with electrographic neonatal seizures and impaired psychomotor development (Oliveira et al. 2000).

Most electrographic neonatal seizures are focal in onset, and seldom generalize. Seizures can originate persistently from one area of the brain or can arise from multiple regions. These are called unifocal and multifocal, respectively. Persistent unifocal seizures are suggestive of an underlying structural lesion in that location (Clancy et al. 1992). The morphology of the electrographic seizures can be variable, ranging from simple sharp waves to complex polyspike discharges to sinusoidal waves. The frequency of the discharge is also variable and can include delta, theta, alpha, and beta frequencies. As any one electrographic seizure discharge progresses, it evolves in frequency and amplitude, and occasionally morphology.

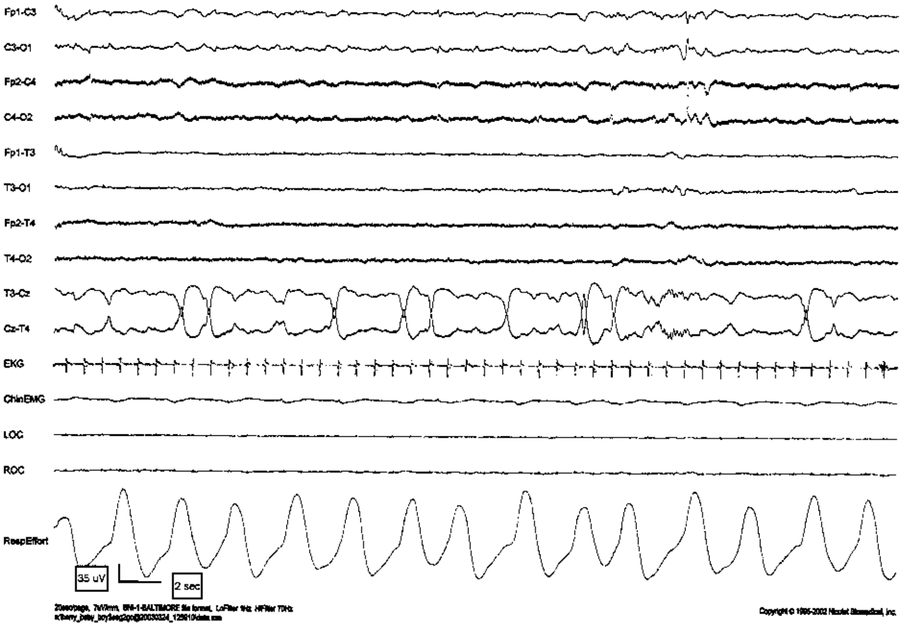

FIG. 11. EEG of a 27 week conceptional age neonate showing excessive focal (vertex) sharp waves.

PRACTICAL NEONATAL EEG ANALYSIS

Prior to reviewing a neonatal EEG, it behooves the interpreting physician to review certain elements of the neonate's history. Foremost is the conceptional age of the neonate. Medical history should also be noted, as should medications that the neonate is receiving. These historical data set expectations for the interpreter of what to expect in the tracing. While reviewing the tracing, attention should be paid to the technologist's notes about the behavioral state of the patient as this is often difficult to gauge from the EEGs of the very young premature neonates. Body movement notations should also be noted as they may provide clues to the behavioral state of the child as well. Notations about the scalp of the neonate are also extremely important. Presence of subgaleal fluid collections or scalp edema can cause an artifactual asymmetry in the EEG.

Neonatal EEGs are routinely reviewed at a paper speed of 15 mm/second, i.e. 20 seconds per page. This allows better appreciation of slow activity and periodicity. Among the first things to note in a neonatal EEG is the continuity of the background activity. The continuity will be dependent on the behavioral state of the neonate. The

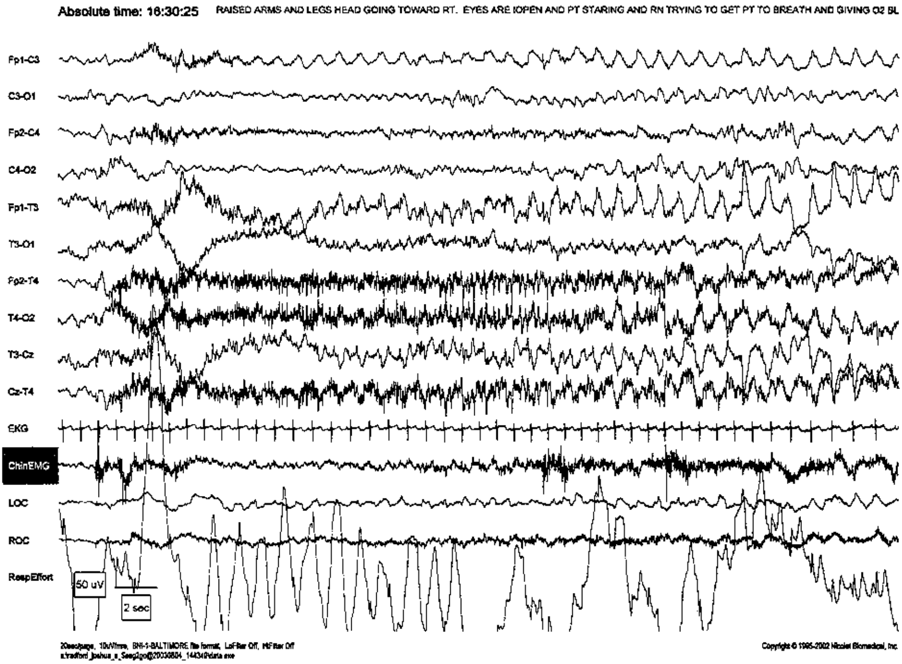

FIG. 12. EEG of a 38 week conceptional age neonate showing an electrographic seizure originating in the left temporal region.

average duration of the interburst intervals should be determined and compared to what would be expected for the neonate's conceptional age. Next the presence of normal features that would be expected for that particular age should be sought. The symmetry and synchrony of these features should be evaluated. The frequency and location of sharp waves should be noted and a determination made as to whether they are normal for age. Finally abnormalities should be sought, such as asymmetries, asynchrony, depressed and undifferentiated background, positive sharp transients, electrographic neonatal seizures, etc.

Interpretation of neonatal EEG poses unique challenges. A clear understanding of typical features that are seen in various age groups is essential for confident and correct interpretation. Serial EEG examinations should be encouraged to determine the true significance of abnormalities, as they are often transient. This is especially important as neonatal EEG are frequently used for prognostic purposes.

Address reprints to: Aatif M. Husain, M.D., Box 3678, 202 Bell Building, Duke University Medical Center, Durham, NC 27710.

REFERENCES

American Clinical Neurophysiology Society Guideline Two: Minimum technical standards for pediatric electroencephalography. J Clin Neurophysiol 1994a; 11:6–9.

American Clinical Neurophysiology Society Guideline Three: Minimum technical standards for EEG recording in suspected cerebral death. J Clin Neurophysiol 1994b; 11:10–13.

Aso K, Scher MS, Barmada MA. Neonatal electroencephalography and neuropathology. J Clin Neurophysiol 1989; 6:103–123.

Aso K, Abdab-Barmada M, Scher MS. EEG and the neuropathology in premature neonates with intraventricular hemorrhage. J Clin Neurophysiol 1993; 10:304–13.

Benda GI, Engel RC, Zhang YP. Prolonged inactive phases during the discontinuous pattern of prematurity in the electroencephalogram of very-low-birthweight infants. Electroencephalogr Clin Neurophysiol 1989; 72:189–97.

Blume WT, Dreyfus-Brisac C. Positive rolandic sharp waves in neonatal EEG: types and significance. Electroencephalogr Clin Neurophysiol 1982; 53:277–82.

Clancy RR. Interictal sharp EEG transients in neonatal seizures. J Child Neurol 1989; 4:30–38.

Clancy RR, Bergqvist AGC, Dlugos DJ. Neonatal electroencephalography. In: Ebersole JS, Pedley TA, editors. Current practice of clinical electroencephalography, third edition. Philadelphia: Lippincott Williams & Wilkins 2003; p. 160–234.

Clancy R, Malin S, Laraque D, Baumgart S, Younkin D. Focal motor seizures heralding stroke in full-term neonates. Am J Dis Child 1985; 139:601–06.

Clancy RR, Tharp BR. Positive rolandic sharp waves in the electroencephalograms of premature neonates with intraventricular hemorrhage. Electroencephalogr Clin Neurophysiol 1984; 57: 395–404.

Dreyfus-Brisac C. Sleep ontogenesis in early human prematurity from 24 to 27 weeks of conceptional age. Dev Psychobiol 1968; 1:162–69.

Dreyfus-Brisac C. Ontogenesis of sleep in human prematures after 32 weeks of conceptional age. Dev Psychobiol 1970; 3:91–121.

Ellingson RJ, Peters JF. Development of EEG and daytime sleep patterns in normal full-term infant during the first 3 months of life: longitudinal observations. Electroencephalogr Clin Neurophysiol 1980; 49:112–24.

Fisch BJ. The normal EEG from premature age to the age of 19 years. Spehlmann's EEG primer. Amsterdam: Elsevier 1991; p. 175–211.

Goto K, Wakayama K, Sonoda H, Ogawa T. Sequential changes in electroencephalogram continuity in very premature infants. Electroencephalogr Clin Neurophysiol 1992; 82:197–202.

Hahn JS, Monyer H, Tharp BR. Interburst interval measurements in the EEGs of premature infants with normal neurological outcomes. Electroencephalogr Clin Neurophysiol 1989: 73:410–18.

Hayakawa M, Okumura A, Hayakawa F, Watanabe K, Ohshiro M, Kato Y, Takahashi R, Tauchi N. Background electroencephalographic (EEG) activities of very preterm infants born at less than 27 weeks gestation: a study on the degree of continuity. Arch Dis Child Fetal Neonatal Ed 2001; 84:F163–67.

Hayakawa F, Okumura A, Kata T, Kuno K, Watanabe K. Dysmature EEG pattern in EEGs of preterm infants with cognitive impairment: maturation arrest caused by prolonged mild CNS depression. Brain Dev 1997; 19:122–25.

Holmes GL, Lombroso CT. Prognostic value of background patterns in the neonatal EEG. J Clin Neurophysiol 1993; 10:323–352.

Holmes G, Rowe J, Hafford J, Schmidt R, Testa M, Zimmerman A. Prognostic value of the electroencephalogram in neonatal asphyxia. Electroencephalogr Clin Neurophysiol 1982; 53: 60–72.

Hrachovy RA, Mizrahi EM, Kellaway P. Electroencephalography of the newborn. In: Daly DD, Pedley TA, editors. Current practice of clinical electroencephalography, second edition. New York: Raven Press, Ltd 1990; p. 201–42.

Lombroso CT. Neurophysiological observations in diseased newborns. Biol Psychiatry 1975; 10: 527–28.

Lombroso CT. Neonatal polygraphy in full-term and preterm infants: a review of normal and abnormal findings. J Clin Neurophysiol 1985; 5:105–55.

Menache CC, Bourgeois BF, Volpe JJ. Prognostic value of neonatal discontinuous EEG. Pediatr Neurol 2002; 27:93–101.

Mizrahi EM, Kellaway P. Characterization and classification of neonatal seizures. Neurology 1987; 37:1837–44.

Monod N, Pajot N, Guidasci S. The neonatal EEG: statistical studies and prognostic value in full-term babies. Electroencephalogr Clin Neurophysiol 1972; 32:529–44.

Novotny EJ Jr, Tharp BR, Coen RW, Bejar R, Enzmann D, Vaucher YE. Positive rolandic sharp waves in the EEG of the premature infant. Neurology 1987; 37:1481–86.

Oliveira AJ, Nunes ML, Haertel LM, Reis FM, da Costa JC. Duration of rhythmic EEG patterns in neonates: new evidence for clinical and prognostic significance of brief rhythmic discharges. J Clin Neurophysiol 2000; 111:1646–53.

Pezzani C, Radvanyi-Bouvet MF, Relier JP, Monod N. Neonatal electroencephalography during the first twenty-four hours of life in full-term newborn infants. Neuropediatrics 1986; 17:11–18.

Scher MS, Aso K, Beggarly ME, Hamid MY, Steppe DA, Painter MJ. Electrographic seizures in preterm and full-term neonates: clinical correlates, associated brain lesions, and risk for neurologic sequelae. Pediatrics 1993; 91:128–34.

Shewmon DA. What is a neonatal seizure? Problems in definition and quantification for investigative and clinical purposes. J Clin Neurophysiol 1990; 7:315–68.

Stockard-Pope JE, Werner SS, Bickford RG. Atlas of neonatal electroencephalography, second edition. New York: Raven Press 1992a; p. 1–51.

Stockard-Pope JE, Werner SS, Bickford RGf Atlas of neonatal electroencephalography, second edition. New York: Raven Press 1992b; p. 105–175.

Stockard-Pope JE, Werner SS, Bickford RG. Atlas of neonatal electroencephalography, second edition. New York: Raven Press 1992c; p. 177–368.

Tharp BR. Electrophysiological brain maturation in premature infants: a historical perspective. J Clin Neurophysiol 1990; 7:302–14.

Tharp BR, Cukier F, Monod N. The prognostic value of the electroencephalogram in premature infants. Electroencephalogr Clin Neurophysiol 1981; 51:219–36.

Tharp BR, Scher MS, Clancy RR. Serial EEGs in normal and abnormal infants with birth weights less than 1200 grams–a prospective study with long term follow-up. Neuropediatrics 1989: 20: 64–72.

Wantanabe K, Iwase K, Hara K. Development of slow-wave sleep in low birthweight infants. Dev Med Child Neurol 1974; 16:23–31.

Watanabe K, Miyazaki S, Hara K, Hakamada S. Behavioral state cycles, background EEGs and prognosis of newborns with perinatal hypoxia. Electroencephalogr Clin Neurophysiol 1980; 49:618–25.