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NEONATAL CEREBRAL FUNCTION MONITORING

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Cerebral function monitoring (CFM) represents a novel technology in the care of neonatal patients that has recently gathered a significant amount of attention as a valuable addition to the diagnostic tools available in the NICU. Although used since 1969 in adults[1], and since 1983 in neonates in Europe[2][3], the value of this device has been disclosed only recently during its use as one of the qualifying criteria in the brain cooling trials for hypoxic-ischemic encephalopathy (HIE) during the neonatal period[4]. From these studies, it became evident that the potential utility of CFM extended far beyond this specific purpose.

CFM, also known as integrated, amplified electroencephalography, or aEEG, represents a bedside, readily available, user -friendly technology for the detection of brain wave activity and the diagnosis of seizures. Through the application of two scalp electrodes that are placed in the temporal-parietal region of the scalp bilaterally and a ground electrode (Figure 1), measured electrical signals can be detected, amplified, integrated, and recorded, yielding valuable information about the overall integrity of the neonatal central nervous system. The use of the device at an infant's bedside is demonstrated in Figure 2.

Although many of the studies to date that have examined the role of CFM monitoring have focused on the infant with HIE[5][6], other studies have evaluated the maturing brain and the changes that occur in the aEEG during post-natal development, especially in the premature infant. In both instances, CFM recording has been shown to add significantly to the clinician's ability to define the potential of an infant for normal development or the possibility of subsequent neurological abnormality. With its growing popularity, CFM will continue to reveal additional insights into the factors that most directly influence neurodevelopmental outcomes in the neonatal population.

The purpose of this paper is to describe the aEEG recording that is obtained during CFM monitoring and to show how it can be used in the management of the pre-term and term infant.

The aEEG Recording

The typical aEEG study is a two channel recording that measures two values primarily (Figure 3). The tracing shown is from an Olympic 6000 cerebral function monitor (Olympic Medical, Inc. Seattle, Washington). While there are several outstanding devices currently available for CFM recording, the author's experience has been primarily with the Olympic Medical analog Lektromed device and the newer digital Olympic 6000, so that the studies shown will reflect the superb results available from these units. Following careful preparation of the scalp, and the placement of either very tiny needle electrodes or gel electrodes in the regions previously noted, the following signals can be shown:

1) The integrated brain wave signal in microvolts on a semi-logarithmic scale, ranging from 0 to 100 mV; and

2) The degree of electrical impedance, on a scale of 0 to 25 kilo-ohms. The impedance demonstrates the quality of the signal that is being received. If impedance exceeds 20 kOhms, the device will set off an alarm to alert the caregiver that the signal is not longer being adequately detected. In most instances, increased impedance reflects a loose lead that needs repositioning.

The impedance channel can be replaced at any time by a raw, scrolling EEG recording, which is particularly valuable when one attempts to determine if a seizure has occurred at any time during the evaluation period (Figure 4).

There are several characteristics of the aEEG tracing that are typically examined:

1) Continuity of the signal

Continuity refers to the consistency of electrical activity. A continuous trace has continuous electrical activity so the CFM trace never goes below about 5 µvolts. A discontinuous trace will have periods of very low, or no electrical activity, allowing the lower margin of the CFM trace to drop below 5 µvolts. Immature infants and infants with HIE will typically have periods of discontinuity, primarily due



Figure 1. (Figure Courtesy of Bob White, MD). Placement of aEEG scalp electrodes and ground electrode. The single ground overlies the frontal region of the scalp, while the recording electrodes are placed in the temporal-parietal region bilaterally).

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Figure 2. Olympic Medical 6000 Cerebral Function Monitor at an Infant's Bedside.

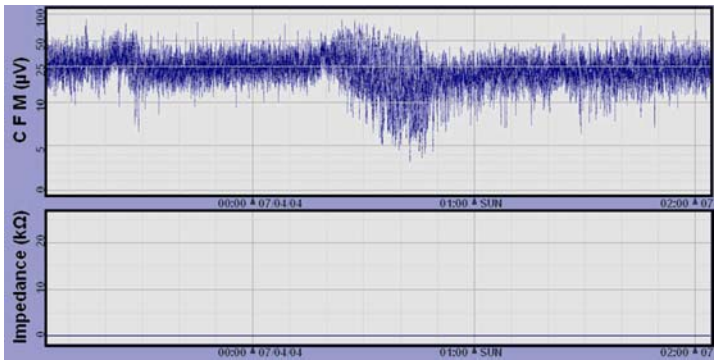


Figure 3. Olympic CFM 6000 Recording (courtesy Ted Weiler, Olympic Medical) The top channel indicates the aEEG in values from 0-100 mVolts, while the bottom channel demonstrates the impedance from 0-25 kilo-Ohms. The aEEG recording is very healthy appearing, with a baseline that is over 5 µV during most of the tracing period, except for a normal segment of cycling. There is no change in impedance throughout the recording and the impedance is very low, indicating a high quality signal for the aEEG.

to the fact that the central nervous system activity is highly variable. There may also be greater numbers of peaks and troughs in the recording, again suggesting the inconsistency of the brain's electrical output during this time period.

2) Bandwidth of the recording

Bandwidth is examined for a number of specific characteristics. In a healthy, normally-developing brain, the lower margin of the dense section of the tracing should reside above 5 mV. Extremely premature infants and term infants with HIE will have a lower level less than 5 mV, reflecting periods of diminished electrical activity in the brain. As a healthy child matures, the bandwidth will continue to rise further from the baseline. The bandwidth will also become increasingly narrowed with normal maturation, whereas it will continue to demonstrate a greater spread in the infant who is not developing appropriately. An abnormal bandwidth is shown in Figure 5, in contrast to the healthier bandwidth appearance of the child seen in Figure 3.

3) Cycling of the recording (Figure 6)

Cycling refers to alterations in the height of the bandwidth and the span of the bandwidth that occur in a recurring manner throughout periods of the recording of a well infant. Although cycling is often referred to in the literature as sleep-wake periods, it is not clear that the epochs during which the recording widens and the baseline lowers do, in fact, reflect a true sleep state. These periods may, instead, simply reflect changes in brain activity or a maturational period during which the aEEG signal is slightly less well organized. Although the signal does deteriorate to some degree during cycling, cycling itself appears to reflect healthy brain development and is viewed as a very positive sign. Infants without cycling (Figure 5) either are very immature or have suffered some degree of injury. The child with an intraventricular hemorrhage (IVH), for example, may lose the ability to manifest brain cycling, as is true for the infant with HIE.

4) Seizures

Seizures often represent ominous events for the neonate. Although seizures can be a consequence of a temporary abnormality during the neonatal period, they often pose significant long-term issues for the neonate, depending upon the etiology of the seizure. In the CFM recording, seizures typically are revealed as a sudden rise in the aEEG. They may be very brief in duration, and these periods may be difficult to capture visually without the assistance of the scrolling EEG on the bottom of the CFM tracing. Typical recurring seizures are demonstrated in Figure 7.

5) Severe hypoxic-ischemic injury (Figure 8)

In the presence of severe neurological injury, markedly diminished overall brain activity may be seen. The overall bandwidth is greatly reduced, the recording rests upon the 0 mV baseline, and periods of sharp, brief spikes may be noted. These recordings have highly ominous implications for the neonate, and it is not uncommon for a significant percentage of these infants to either die or manifest profound long-term neurological handicap.

Use of the CFM Recording

As indicated in the descriptions of the recordings, the CFM monitor can be used in a variety of ways in the assessment of neonatal neurological development and injury. Most studies to date have focused upon the child with hypoxic-ischemic injury. With HIE, the term or near-term infant's aEEG patterns reveal the following sequence of events with progressive injury:

1. Loss of cycling
2. Broadening of the bandwidth and reduction of the baseline level for the recording
3. Seizures

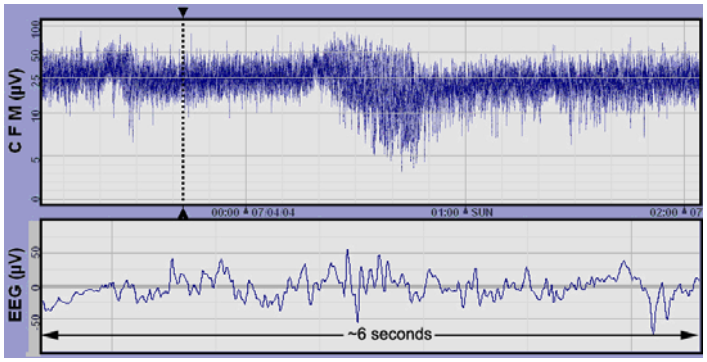


Figure 4. (Courtesy Ted Weiler, Olympic Medical) A CFM recording in which the lower channel has been replaced by a continuous EEG tracing, taken at the point of the dashed line in the upper, aEEG recording.

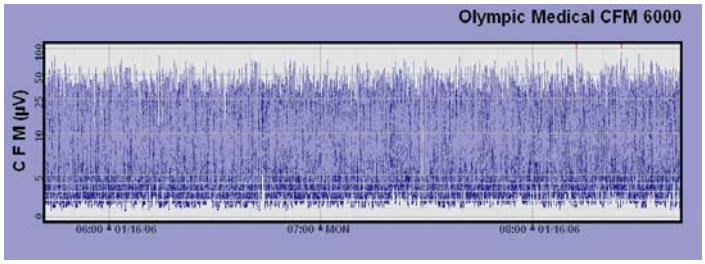


Figure 5. (Courtesy Ted Weiler, Olympic Medical) A CFM recording in a child with hypoxic-ischemic encephalopathy that demonstrates a broad bandwidth and an extremely low margin residing near 0 µV at the baseline.

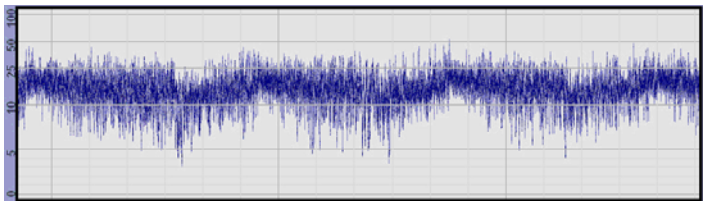


Figure 6. Cycling in a healthy infant. The baseline is well above 5 µV and narrow, except for the periods during which the tracing widens and descends slightly. This is considered to be a normal, healthy pattern.

4. Burst-suppression appearance with decreased overall electrical activity and spikes

With recovery (though recovery may be limited with the severe forms of injury), there is a step-wise reverse change in the aEEG recording. The faster that this reversal occurs, the better is the long-term prognosis for the infant. A neonate who returns to normal cycling on the aEEG within 24-48 hours with baseline elevation above 5 mV has a much better prognosis than an infant in whom there is no reversal before 7-10 days. Infants who have had a difficult delivery, but who show few changes in their aEEG pattern, have a good prognosis overall.

In the pre-term infant, the aEEG is somewhat less well understood at the present time, since there is an interesting similarity of findings in the normal very immature infant and the child with HIE. More work needs to be done, however, to define the aEEG findings with respect to neurological abnormality and recovery from injury in premature infants.

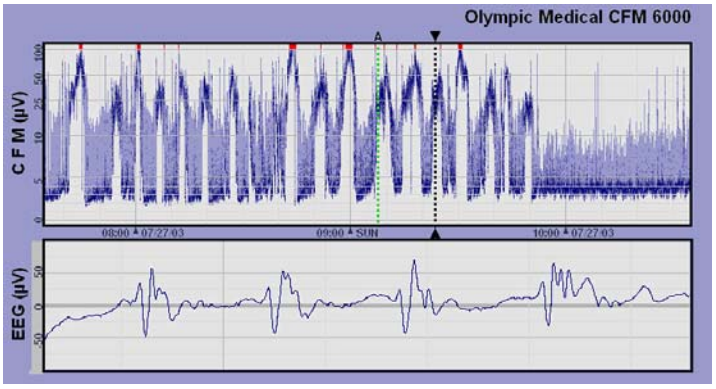


Figure 7. (Courtesy Ted Weiler, Olympic Medical) Recurring seizures on the aEEG recording in a term infant with hypoxic-ischemic injury. Seizures, with elevation of the entire recording, are seen throughout the aEEG tracing. The lower recording shows the classic spike and slow wave appearance of a seizure in the bottom part of the recording. The EEG recording reflects a six-second time duration at the point of the black dashed line seen in the upper recording.

The premature infant's aEEG patterns can, nevertheless, be examined for the rate of change expected in normal maturation. Burdjalov has described the events that occur during neonatal neurological maturation, as well as a scoring system which can be used to chart this maturation in the premature baby (Figure 9)[7]. Children with IVH appear to have a flatter slope and do not mature their aEEG patterns as rapidly, in general, as do preterm neonates without an IVH or PVL. More work needs to be done, however, as previously noted, since premature infants have not been extensively studied to date.

The CFM can also be used to follow the results of treatment with anticonvulsants in the case of neonatal seizures. Normalization of the aEEG is highly reassuring when a child has previously been diagnosed with a seizure disorder.

Summary and Speculation

The CFM recording appears to be a valuable addition to the armamentarium of the neonatologist in attempting to understand the factors that influence normal neonatal development, the severity of brain injury from HIE and IVH, and the likelihood of recovery from these entities. Further work is likely to reveal additional insights into brain development in the neonate with this device, and it is far from inconceivable that the neonate may one day be monitored for central nervous system integrity in the same way that we currently monitor cardiorespiratory changes in the heart and lungs. The aEEG appears to be an important tool that allows the neonatologist and neonatal nurse to better understand the changes that commonly occur in the brain during the neonatal intensive care hospitalization.

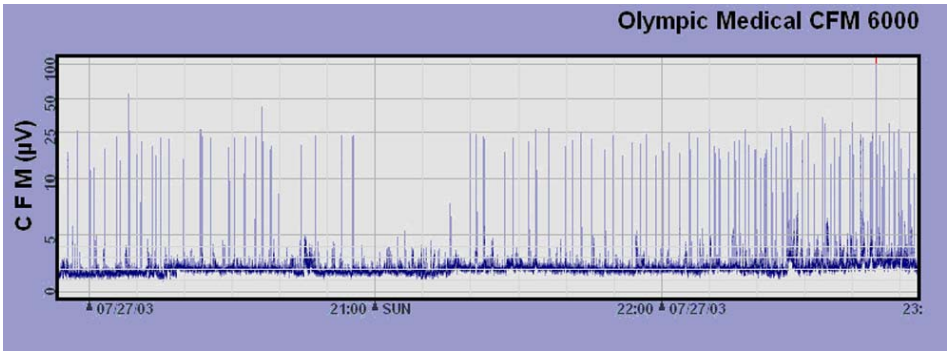


Figure 8. (Courtesy Ted Weiler, Olympic Medical) Severe hypoxic-ischemic injury with burst-suppression on the aEEG recording. Little cerebral activity, low baseline, and frequent spikes are seen.

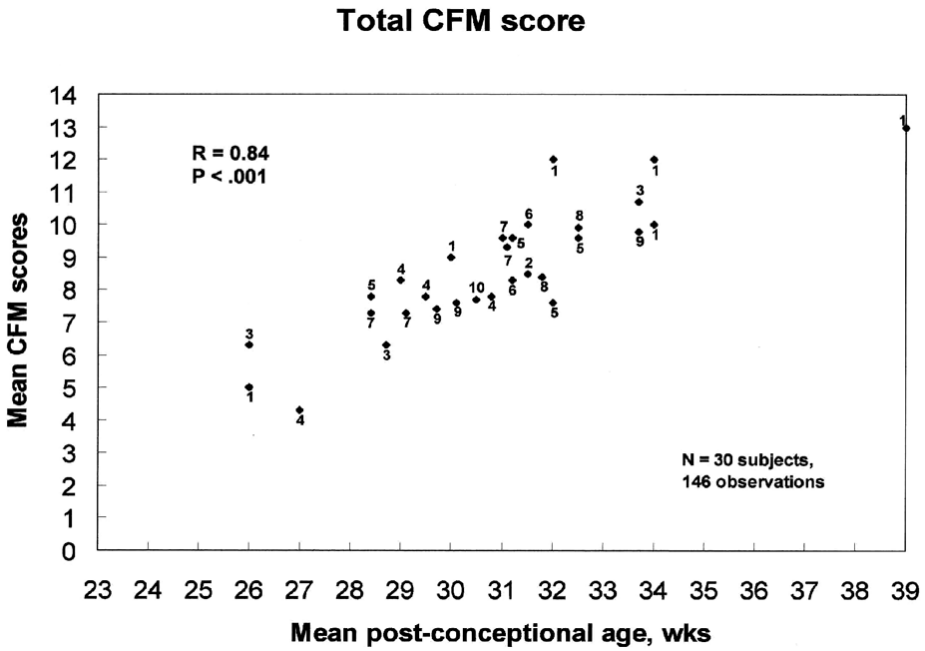


Figure 9. Scoring system for maturation in premature infants with aEEG recording. Reprinted with permission from Pediatrics (http://pediatrics.aappublications.org), Burdjalov VF, Baumgart S, and Spitzer AR: Cerebral Function Monitoring—a new scoring system for the

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