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Low Voltage aEEG as predictor of Intracranial Hemorrhage in preterm infants

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Abstract

The objectives of this prospective cohort study were to identify amplitude-integrated electroencephalography (aEEG) background patterns predictive of severe intracranial hemorrhage. Thirty ventilated preterm newborns <1000 grams were assessed using an aEEG cerebral function monitor and ultrasound measurement of cerebral blood flow (CBF) velocity at time of surfactant administration and tracheal suctioning simultaneously during first 48 hours of life. Birth weight was 624 ± 200 g (mean $\pm$ SD) and gestational age was 25 ± 2 weeks. Background electrical activity was predominantly discontinuous in 72% of infants. A sharp increase in electrical activity/burst density was observed during surfactant administration and tracheal suctioning in most infants with a 33.5 % increase in mean CBF velocity. Burst suppression with low voltage was identified in 57% infants with grade 3-4 Intracranial hemorrhage, while no infant without hemorrhage exhibited this pattern ($P = .014$). We conclude that aEEG low voltage burst suppression might have useful clinical applications with 100% positive value for severe intracranial hemorrhage.

Introduction

Amplitude-integrated electroencephalography (aEEG) provided by a cerebral function monitor is being introduced in neonatal intensive care units as a quick and easy bedside alternative for monitoring of sick infants. Specifically, we [1] and others [2-4] have reported good aEEG predictive value in the diagnosis of severity of hypoxic-ischemic encephalopathy and in the selection of term infants most likely to benefit from hypothermia treatment.

In contrast to the use of aEEG in term infants, the interpretation of aEEG tracings in very preterm infants is more problematic. Firstly, aEEG background activity changes from a discontinuous to continuous pattern as preterm infants mature. Additionally, preterm infants require more medications and procedures that may affect the background electrical activity. Despite these limitations, the rationale for continuous brain monitoring in preterm infants, who may be sedated and/or may be unable to show clinical signs of neurological compromise, is very appealing [5]. With future development of targeted neuroprotective interventions for preterm infants, the aEEG may help define the population most likely to benefit from treatment. There is a definite need to evaluate real-time aEEG parameters that

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could be easily detected at the bedside by simple pattern recognition that might aid clinicians in the early detection of ICH.

The objectives for this prospective pilot study of aEEG recordings in extremely low birth weight (ELBW, birth weight ≤ 1000 g) newborns during the first 48 hours of life were to assess background electrical activity, the effect of procedures on background electrical activity, and to determine patterns predictive of severe intracranial hemorrhage (ICH).

SUBJECTS AND METHODS

Study Design

This was a prospective pilot study conducted at a regional perinatal center in a rural state. Participants were consecutively enrolled from January to July 2007. The University of Arkansas for Medical Sciences IRB approved the study protocol. Informed consent was obtained from parents prior to study participation.

Participants

Inborn infants with birth weight 401–1000 g, gestational age 23 0/7 to 28 0/7 weeks', and those who were mechanically ventilated and administered surfactant for respiratory distress syndrome were all included. ELBW infants with central or parietal scalp abnormalities, presence of known or suspected congenital anomalies, and those *in extremis* were excluded.

Procedures and Equipment

Cranial ultrasounds were obtained on day of life 1 prior to starting aEEG monitoring, and on days 3-5 and days 10-14. Severe ICH was defined a priori as Grade III or IV intraventricular hemorrhage (IVH) and/or large cerebellar hemorrhage. Grading of IVH was described by a single radiologist who was blinded to the study and used the Papile et al [6] classification below:

- Grade I – blood isolated to the germinal matrix
- Grade II – blood within the lateral ventricles without ventricular dilatation
- Grade III – blood within and lateral ventricles with ventricular dilatation
- Grade IV – blood within the lateral ventricles and parenchymal hemorrhage

aEEG—Monitoring was performed on a Lectromed Cerebral Function Monitor (Olympic Medical Corp., Seattle, WA) from 2 fronto-parietal adhesive gel electrodes (C3-P3). Recording was started 15 min before a procedure and concluded 45 min after the procedure for a total recording of 1 hour. The aEEG tracing was displayed on an integral printer at 6cm/hour recorded on a semi-logarithmic scale from 0–100 μv . Impedance was continuously recorded and tracings with impedance > 10 were not utilized. The aEEG recording was begun at 6 hours of life during the second dose of surfactant. Additional aEEG tracings were obtained at 12 hours of life (if a third dose of surfactant was administered) and on the second day of life before and after clinically indicated tracheal suctioning. Tracings were marked at the beginning and end of surfactant administration and suctioning.

Background electrical activity was classified a priori according to Hellström-Westas, et al [7]: *Continuous*: continuous electrical activity with minimum amplitude 7–10 μv , and maximum amplitude 10–25 μv . *Discontinuous*: discontinuous background with variable minimum amplitude < 5 μv and maximum > 10 μv . *Burst suppression*: lower amplitude without variability at 0–1 μv , with bursts of amplitude > 25 μv . *Flat Tracing*: iso-electric with background < 5 μv , with or without burst suppression.

CBF velocity—Continuous measurements of right middle cerebral artery CBF velocity were made using a transcranial Doppler ultrasound system (Nicolet Biomedical Pioneer, Madison, WI) for 1 hour, 15 minutes before and 45 minutes post-procedures as described in details in a previously published surfactant and suctioning study [8-9]. The 2 MHz transducer was placed transtemporally anterior to the external ear and above the zygomatic arch and held in place by an appropriately sized crocheted hat (provided by the Arkansas Extension Homemakers Council). A depth of 16–22 mm was used to study the middle cerebral artery with very low ultrasound intensity (5–21 mW/cm²). Transducer placement was optimized when the highest acoustic signal was perceived and the brightest Doppler spectra were visualized.

Surfactant—Surfactant administration and tracheal suctioning were performed at the discretion of the attending neonatologists and bedside nurses according to neonatal intensive care unit guidelines. Beractant (Abbott Laboratories, Columbus, OH) was administered via a multi-access catheter (Kimberly-Clark Ballard Neonatal Trach Care MAC Catheter, Draper, UT) connected to the endotracheal tube and inserted to just above the carina. A total dose of 4 ml/kg (100 mg/kg) was administered in 4 bolus aliquots according to the manufacturer's recommendations and as previously reported [8]. Pre-treatment ventilator settings were maintained during surfactant therapy, and were manipulated only if clinically indicated.

Open tracheal suctioning [9]—This was performed on ELBW infants only when clinically indicated. The oral 2.5 mm endotracheal tube was disconnected from the ventilator circuit and an appropriately-sized suction catheter was sterilely inserted to just above the carina. Wall suction (80–100 cm H₂O) was applied to the catheter, which was withdrawn with one consistent movement, taking ~10 seconds. The endotracheal tube was then reconnected to the breathing circuit with pre-suction ventilator settings maintained. The process was repeated once or twice more until the airway was clear.

Statistical Analyses—Data are presented as mean $\pm$ SD or median (25th–75th percentiles) where appropriate. Statistical analysis was performed using Sigma Stat 3.0 (SPSS, Chicago, IL). T test was used to test differences between the group with and the group without ICH. Fisher exact test was used for categorical variables such as need of pressors and ICH. The predictive values of low voltage background electrical activity with burst suppression in relation to development of severe ICH were calculated using sensitivity, specificity, and positive and negative predictive values. For CBF velocity, mean percent change from baseline was calculated from measurements during surfactant administration and suctioning.

RESULTS

The birth weight was 624 ± 200 g, the gestational age was 25 ± 2 weeks, and other clinical characteristics for the 30 infants are illustrated in Table 1. Additionally, all these infants received Fentanyl PRN as needed for sedation while mechanically ventilated, 4 infants received dopamine infusions for hypotension, 1 infant required insulin for hyperglycemia, and 2 infants underwent cardiopulmonary resuscitation during newborn resuscitation. None of the infants had any clinical seizures. Two infants had Grade I-II IVH. Severe ICH occurred in 7 (23 %) infants. In this ELBW population, infants with severe ICH had no significant differences in any of the variables listed in Table 1, such as gestational age, birth weight, cord pH, or PCO₂.

aEEG

Initial tracings were mostly discontinuous (76%). Three (10%) infants had continuous tracings while 4 (16%) had isoelectric tracings with burst suppression (total band width of $<1 \mu\text{v}$) on tracings obtained in the first day of life. Median values for all aEEG tracings were 3–4 μv for the lower band sleep wake range, and 6–25 μv for the higher band sleep wake range.

Surfactant administration and tracheal suctioning were associated with either no background electrical activity changes, or brief increases of burst activity of <10 minutes duration. In the latter cases, sharp increases in electrical activity (5–10 μv) with increased burst density were observed during surfactant administration and suctioning in most infants, as well as a 33.5 % (range 11.1% to 150%) increase in mean CBF velocity. A concomitant artifact signal (see impedance tracing) was also seen in most infants during the procedure (Fig 1). These effects were transient and did not affect the overall tracing background interpretation. After procedures, background electrical activity and CBF velocity returned to baseline. Blood pressure was stable for the 1 hour duration of the recordings, but 5 infants received dopamine infusions for hypotension (4 of these had severe ICH). Infants with severe ICH were more likely to require infusion with pressors for hypotension prior to the aEEG recording ($p = 0.006$).

Predictive Values for ICH

aEEG parameters for infants without and with severe ICH are shown in Table 2. Infants who developed ICH tended to have lower electrical activity in both the lower and higher bands. Moreover, the burst suppression pattern with a straight lower margin of 0–1 μv and low electrical activity with a band width of 1 μv was seen in 4 of the infants who developed severe ICH, and in none of the infants with normal cranial ultrasound findings ($P = .014$). Of the 7 infants who developed ICH, 4 had low voltage burst suppression, 3 had discontinuous low voltage, and none had a continuous tracing. Predictive values for the burst suppression pattern in relation to developing severe ICH were as follows: 100% positive predictive value, 85% negative predictive value, 57% sensitivity, and 100% specificity. The calculated relative risk of 7 with 95% CI (2–20) for developing severe ICH in the presence of low voltage burst suppression was statistically significant.

Despite the small number of infants who developed severe ICH, temporal patterns related to timing of the bleeding were available due to the serial cranial ultrasounds starting on the first day of life. Severe ICH was detected on the first day of life in only 1 infant who had an isoelectric flat tracing and died at 13 hours of life. The remaining 6 infants who developed ICH were detected on the day of life 3–5 ultrasound. Three infants, other than the one who died, had an isoelectric burst suppression pattern before the second ultrasound revealed the ICH. The three other newborns that developed severe ICH had decreased lower band amplitude electrical activity.

DISCUSSION

This prospective pilot study of intubated and mechanically ventilated ELBW infants showed the following key findings: most infants displayed a discontinuous tracing that was briefly disrupted during surfactant and suctioning procedures; most importantly, we observed that the aEEG low voltage burst suppression pattern was an ominous predictor, with 100% positive predictive value, for developing severe ICH.

This study focused on the description of the aEEG electrical background activity in newborn ELBW infants. Importantly, aEEG background electrical activity can easily be interpreted at the bedside by neonatologists trained in aEEG pattern recognition [7] and may be reflective

of short-term poor prognosis. We used a priori the Hellström-Westas [7] classification system to allow for generalizability of our findings. Previous studies using a semi-quantitative description of the maturational changes in extremely preterm infants reported a progression from a mostly discontinuous low voltage pattern without sleep cycling to a more continuous pattern with the emergence of sleep wake cycles and a narrowing of the inter-cycle bandwidth [10-15]. Consistent with these studies, most of our ELBW newborns had discontinuous tracings, while some also had a burst suppression pattern with inactive lower band tracing.

Most infants had increased electrical excitability on aEEG during surfactant administration and suctioning. We previously reported [8-9] during both the second dose of beractant and during tracheal suctioning in very low birth weight infants a significant increase in middle cerebral artery CBF velocity. This CBF velocity increase has been described previously to be predominantly related to changes in PaCO₂ and not to changes in mean arterial blood pressure, i.e., most infants presumably had intact cerebral auto regulation [9]. The current study further supports this concept, as evidenced by the absence of electrocortical depression that has been reported in other studies during surfactant treatment [16-18]. These latter surfactant studies where poractant was used have reported 10–20 minute decreases in electrocortical activity and a simultaneous decrease in mean arterial blood pressure. We speculate lack of electro cortical depression in our current study was concordant with the observed unchanged stable mean arterial blood pressure during beractant administration. Discrepancies between our results compared to others may be related to the use of beractant vs. poractant, differences in surfactant administration protocols, as well as differences in patient populations being studied.

The third and most important finding in the current study relates to the usefulness of the aEEG recording, specifically the presence of the low voltage burst suppression pattern, to detect ongoing or developing brain injury in newborn ELBW infants. Others [19-22] have correlated aEEG abnormalities with structural brain damage including, hydrocephalus and IVH. Prognostic aEEG factors such as the number of bursts have also been shown to predict death or severe neuromotor impairment in infants with grade 3 or 4 IVH [23]. Another factor found to be associated with IVH is the delayed recovery of low voltage background otherwise expected with increasing maturity [24]. Depressed voltage background activities with decreased amount of continuous activity, epileptic seizures, and burst density have all been reported in infants who had large IVHs [20-25]. A more recent aEEG study using both visual analysis and quantitative analysis software reported that decreased aEEG continuity (<80% continuity at 10 μ v) was a strong predictor of poor short-term outcome by identifying 83% of infants who died or had severe IVH [26]. Since this software is not generally available for clinical use, and requires offline analysis, we elected in our study to focus on simple pattern recognition using an internationally recognized classification scheme that can be widely applicable in real-time to clinical neonatologists.

Strengths of this study are: the prospective design focusing on early assessment of a previously unstudied homogeneous inborn population of newborn ELBW infants requiring surfactant treatment for respiratory distress syndrome, the serial monitoring around neonatal intensive care procedures, and the blinded interpretations of tracings in relation to occurrence of ICH by one of the authors (LC).

We acknowledge the following limitations due to our study design: small sample size in this pilot study, tracings were obtained intermittently rather than continuously, tracings were not available beyond 48 hours of life, the focus was solely on background electrical activity, and the study did not include long-term follow-up. Despite these limitations, we were able to find that low voltage discontinuous activity with burst suppression was an ominous finding

predicting the occurrence of severe ICH with 100 % positive predictive value and specificity. Moreover, caution should be used in the interpretation of aEEGs in ELBW infants due to the predominance of discontinuous tracings and the transient effect of neonatal interventions as seen with suctioning and surfactant administration. The low sensitivity of a low voltage with burst suppression might be related to the interplay of complex pathophysiological changes associated with severe intracranial hemorrhage. Any acute change in cerebral perfusion or metabolism can potentially affect the continuity of aEEG, such as profound hypoglycemia, or metabolic disorders. Administration of opioids or antiepileptic especially in critically ill newborns could lead transiently to low voltage burst suppression, and has been reported following infusions of morphine, lidocaine or Phenobarbital [27-28].

Our study suggests that finding low voltage burst suppression pattern should prompt an immediate cranial ultrasound for confirmation due to the high likelihood reported. This pattern, however, is not a necessary finding for predicting severe ICH as shown by the observed lower sensitivity, and should by no means be a replacement for scheduled routine cranial ultrasounds during the neonatal period. Rather than an alternative diagnostic tool for severe intracranial hemorrhage, we suggest that aEEG is an acceptable bedside screening device to prompt immediate medical attention, in the middle of night to the child condition. Clinical acumen about other hemodynamic changes that might be occurring can help next paradigm for decision making.

With updated development of digital equipment, new generation monitors can record variable number of channels with simultaneous EEG and aEEG, further closing the gap between the two devices. This article adds information on limitation and utility of the aEEG in extremely low birth weight infants while this technology is already making rampant use in neonatal intensive care settings.

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Figure.1. aEEG background sample tracings of 1 hour duration at time of surfactant administration and suctioning

1. A) Continuous activity; 1.B) Discontinuous activity; 1.C) Isoelectric activity with burst suppression. The effect of neonatal procedures is marked in red by the arrows and circle sign. The line below the tracing displayed on the semi logarithmic scaling is indicative of impedance and was kept under 10 Ohm.

Table 1

Infant Characteristics

Characteristics	Data
Birth weight (g)	624 ± 200
Gestational age (weeks)	25 ± 2
Surfactant (≥2 doses)	100%
Antenatal steroids	100%
Vaginal delivery	57%
Twins	10%
Female gender	53%
Race	63% White, 30% Black, 7% Hispanic
Apgar 1 minute	2 (1–4)
Apgar 5 minutes	6 (4–7)
Cord PH or First arterial PH	7.25 (7.14–7.3)
Base Deficit on first arterial sample	6 (4–10)
CO ₂ at time of aEEG recording	49 (38–63)

Data presented as mean ± SD, percentage, or median (25th–75th percentiles), where appropriate.

Table 2

Amplitude EEG Findings

	No ICH (n = 23)	Severe ICH (n = 7)
Low band range	4 (2–5)	1 (1–3)
High band range *	10 (5–25)	2 (2–5)
Low voltage burst suppression *	0%	4 (57%)

Data presented as median (25th–75th percentiles), or number (percentage),

* $P < .02$