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REGULAR ARTICLE

Overcoming the practical challenges of electroencephalography for very preterm infants in the neonatal intensive care unit

RO Lloyd[1,2], RM Goulding[1,2], PM Filan[1,2], GB Boylan (g.boylan@ucc.ie)[1,2]

1.Neonatal Brain Research Group, Irish Centre for Fetal and Neonatal Translational Research (INFANT), University College Cork, Ireland
2.Neonatal Intensive Care Unit, Cork University Maternity Hospital, Wilton, Cork, Ireland

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Correspondence
G B Boylan, Neonatal Brain Research Group, Irish Centre for Fetal and Neonatal Translational Research, Department of Paediatrics and Child Health, Cork University Maternity Hospital, Wilton, Cork, Ireland.
Tel: +353 21 420 5040
Email: g.boylan@ucc.ie

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ABSTRACT

Aim: Long-term electroencephalogram (EEG) recording is increasingly being used in the neonatal period, but application and maintenance of the EEG electrodes is challenging, especially in preterm infants. This study proposes a practical method of electrode application that can be used in the neonatal intensive care unit (NICU).

Methods: EEG recording in preterm infants of <32 weeks of gestational age is often challenging and requires careful preparation and strict adherence to NICU protocols. An effective technique for EEG application in preterm infants is to use prepackaged, sterile, disposable, flat-surfaced EEG electrodes. The use of these electrodes in combination with a continuous positive airway pressure hat provides good security for electrodes and good quality EEG recordings. It also limits the handling of the infant, while strictly adhering to infection control policies.

Results: Long-term monitoring for >72 h has been achieved using this technique. Important steps to consider are efficient preparation of the recording machine and materials, careful electrode application and infection control.

Conclusion: A fast and effective method of EEG electrode placement is required for neonatal EEG monitoring. The practical techniques described in this article outline a reliable method of EEG electrode placement, suitable for even extremely preterm infants.

INTRODUCTION

The value of electroencephalography (EEG) monitoring is well established in full-term infants, particularly for seizure detection and treatment, grading the severity of encephalopathy and prognostication (1–4). There is now significant interest in exploring and defining the clinical utility of continuous EEG monitoring in preterm infants (5). This is particularly important, because preterm infant survival is improving, but the rate of disability remains high (6). In addition, recent studies of early amplitude-integrated EEG monitoring in extremely preterm infants suggest that seizures are prevalent in the first week of life (7). Prognosis following seizures in preterm infants has also been investigated (8).

The use of EEG for monitoring the function and maturation of the preterm brain is growing (9). EEG electrode application in this population is difficult and challenging, due to the small head size and the limited space within a humidified incubator. In addition, these infants frequently require respiratory support and head caps are often used to secure respiratory devices, such as a continuous positive airway pressure (CPAP) hat. Strict infection control and hand hygiene guidelines must be adhered to and standardising the technique for electrode application, without affecting the quality of EEG recordings, is essential and would be welcomed.

The aim of this study was to review existing EEG electrode application techniques for infants and propose a more practical method that can be utilised in the neonatal intensive care unit (NICU) setting, while ensuring minimal interference in the clinical care of the preterm infant.

Abbreviations
CPAP, Continuous positive airway pressure; EEG, Electroencephalogram; NICU, Neonatal intensive care unit.

Key notes
- Long-term electroencephalogram (EEG) recording is increasingly being used in the neonatal period, but application and maintenance of the EEG electrodes is challenging, especially in preterm infants.
- This article describes a simple, effective and safe method for EEG application, suitable for clinical use in even the most preterm infants.
- Good preparation, infant-friendly disposable flat-surfaced electrodes and organisation of the electrodes within the incubator help maximise data quality.

METHOD

Prior to refining our proposed method, we reviewed techniques currently used in the NICU to assess their suitability for preterm neonatal EEG acquisition. Walls-Esquivel et al. provided a valuable overview of their preferred approach for EEG application and used EEG disc/cup electrodes for their recordings (10). There are also other electrode types available, including subdermal needle electrodes, disposable flat-surfaced electrodes and the more recently developed neonatal electrode caps.

EEG cup electrodes

Standard silver/silver chloride or gold EEG cup electrodes are widely used for EEG monitoring (Fig. 1A). Gentle scalp scarification with an abrasive gel is required prior to electrode placement, and a conductive paste is used to produce good quality recordings. These electrodes are effective and widely used in adults and children. However, problems do arise with prolonged use in infants, as scalp abrasions and indentations have been reported (11). Disposable cup electrodes have the advantage of being sterile, but still pose the risk of scalp compromise.

Subdermal needle EEG electrodes

The needle penetrates the subdermal layer of the scalp and records the EEG activity precisely at that localised site. This generally produces good quality recordings with low impedances (Fig. 1B). This technique is routinely used in NICUs across Europe, primarily for amplitude-integrated EEG monitoring, and while the advantage of quick application is evident (12), it is clearly invasive and the skin barrier is broken, posing a possible infection risk to preterm infants (13). The American Clinical Neurophysiology Society's Guideline on Continuous EEG Monitoring in Neonates does not recommend the use of needle electrodes in infants (14).

Prepackaged, sterile, disposable, flat-surfaced EEG electrodes

A number of sterile, disposable, flat-surfaced EEG electrodes are available and provide an attractive option for neonatal EEG monitoring (Fig. 1C) (15). They have the obvious advantages of being sterile, flat, adhesive and leave no indentations on the skin. However, the scalp still needs to be prepared prior to application to reduce the impedance. These electrodes have a large surface area (20 x 15 mm), much larger than cup electrodes, and may cause electrode bridging on a small head. Conversely, if applied correctly and positioned accurately, bridging should not occur.

Electrode caps

A number of adult EEG electrode caps have been developed, which have proved useful for EEG monitoring. As a result, some neonatal caps are currently under trial (Fig. 1D) (16). In theory, a predesigned cap, which already includes prepositioned electrodes seems ideal. However, skin preparation is still required to produce good quality recordings. In addition, as head size varies according to gestational age, a number of different sized head caps would be required to provide accurate positioning of electrodes. Many of the currently available electrode caps also need to be secured tightly under the chin, which is not ideal for preterm infants. Pressure marks have been described on the scalp of infants wearing electrode hats for as short as a 1 h period, but newer textile type electrodes for caps are in development, which may prove more suitable for infants (11).

Guidelines for recording EEG in full-term infants were recently created by the NEMO Consortium and

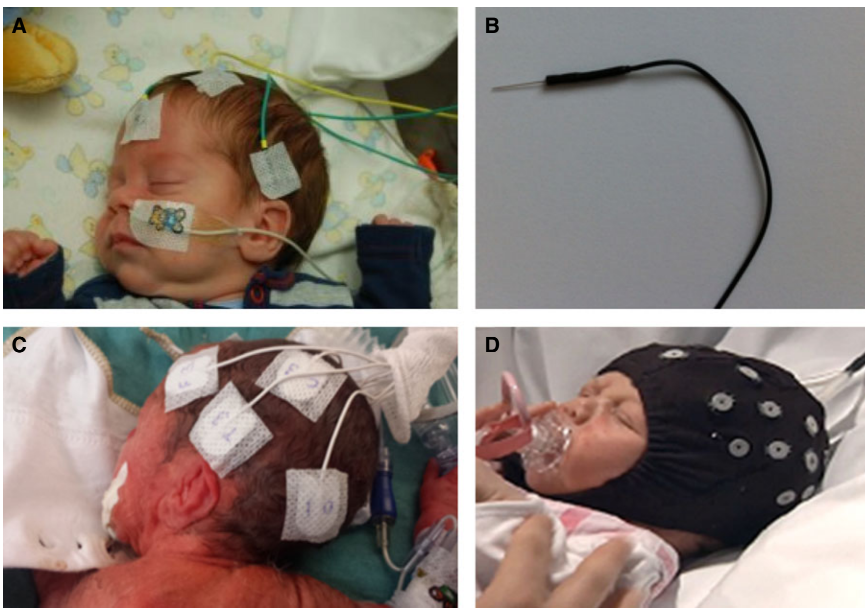

Figure 1 EEG electrode options. (A) Cup Electrodes. (B) Needle Electrodes. (C) Disposable Electrodes. (D) Electrode Caps.

include a widely accessed online multimedia tool designed for neonatal EEG application and monitoring (http://www.nemo-europe.com/en/educational-tools-for-clinicians-and-health-care-professionals.php).

From the review of currently available methods for neonatal EEG recording, we concluded that an optimal method for EEG monitoring in very preterm infants is not available. We therefore developed a technique using prepackaged, disposable, sterile, flat-surfaced electrodes, which to date have produced 136 high-quality, long-term EEG recordings of up to 72 h in 70 infants of <32 weeks gestational age. The mean gestational age of the 70 infants was 28+6 weeks, with a standard deviation of 2 weeks. The age range at the time of first recording in each infant was between one and 29 h (mean 8 h and 34 min), and 42 of the 136 recordings were during CPAP use (31%). The EEG application procedure was timed in 10 cases, and the average time required to apply the electrodes in the incubator was 12 min.

EEG electrodes were applied by trained EEG technologists or medical personnel. The method was easily adopted by staff in the unit, following two or three training sessions. Prior to the application of EEG electrodes, close consultation with NICU personnel is recommended to ascertain policies and procedures that must be adhered to while in the NICU environment and to ensure that the health, safety and well-being of the preterm infant is not compromised in any way during handling and application. The step-by-step procedure is outlined below.

EEG application procedure

Adequate preparation is paramount to the success and efficiency of the procedure. Strict hand hygiene is mandatory within the NICU environment; therefore, hands must be washed in line with the hand hygiene protocol prior to handling of any EEG materials. Surfaces must also be cleaned before use in accordance with local guidelines (17). The materials required are as follows:

- Disposable, sterile, flat-surfaced electrodes. These should have an ideal dimension of 15×20 mm, and a measuring area of 263 mm^2. Due to the small head size, the surface area of the electrodes needs to be small. Ambu Neuroline 700 Single Patient Surface Electrodes were used for our technique. The estimated cost of a single pack of 12 electrodes is eight Euros plus value added tax.
- EEG Machine. Any EEG system can be used to follow this procedure. In our centre, three machines were used effectively (Nihon Koden, EEG-1200, Neurofax; NicoletOne, ICU Monitor, NeuroCare, Carefusion and Moberg ICU Solutions, CNS-200 EEG and Multimodal Monitor).
- Coloured pencils. Colour coded, prelabelling of the electrodes for each hemisphere minimises possible human error during electrode application. In addition, prelabelling helps with a more systematic approach to applying electrodes, and ensures the application is less time consuming and more efficient.
- Adhesive medical tape (Mefix). Electrode contact weakens in the high humidity of the incubator, therefore securing the electrode with a small square piece of tape minimises loss of contact. Ten20 paste can be applied to the tape, if required, to enhance adhesion.
- Stockinette. EEG electrode cables are secured together, in an orderly fashion, within a stockinette or other suitable tubing.
- Skin prep gel. This improves conductivity.
- Sterile tongue depressor. Facilitates clean transfer of electrode paste.
- Sterile cotton buds. Utilised in conjunction with the skin prep gel to minimise the impedance of skin.
- Sterile galipot. Provides a sterile container for the skin prep gel and Ten20 paste.
- CPAP hat. Provides electrode security.
- Disposable gloves.

The materials required should be organised prior to electrode preparation. The international 10/20 system (Fig. 2A) of EEG electrode placement, modified for infants, should be followed, as described in the American Clinical Neurophysiology Society Guidelines (14). We prefer to use the F3/F4 electrode positions instead of the standardised prefrontal positions (Fp1 & Fp2), located more anteriorly, as we have found that the F3/F4 electrodes are less susceptible to falling off in the humid incubator environment. In addition, we routinely use near-infrared spectroscopy monitoring, which requires a sensor over the frontal region. It should be appreciated that using the F4/F3 electrode, the amplitude of the EEG in a longitudinal bipolar montage (between F3-C3 and F4-C4) will be reduced, in comparison with the amplitudes recorded over C3-O1 and C4-O2 channels, due to unequal interelectrode distances. However, whichever electrodes are used to record the EEG, it is imperative to ensure that interelectrode distances between hemispheres are equal.

Electrode preparation

- Prepare and organise the required equipment on a clean work tray placed on a clean trolley. The trolley and work tray must be cleaned with disinfectant wipes or a similar alternative, in accordance with local guidelines, before proceeding. All materials required will be placed in the clean work tray, once organised.
- Allocate an electrode set to the right cerebral hemisphere and label F4, C4, T4 and O2. Allocate another to the left hemisphere labelled F3, C3, T3 and O1. Label three more electrodes as reference, ground and Cz (Fig. 2B).
- Cut some Mefix tape and apply to each corresponding electrode plug, correspondingly labelled (Fig. 2C).
- Cut an appropriate length of stockinette and feed the electrodes through it to keep them in order (Fig. 3A). This reduces electrode entanglement and 50 Hz artefact interference.
- Insert the electrode plugs in their designated sockets in the EEG amplifier.

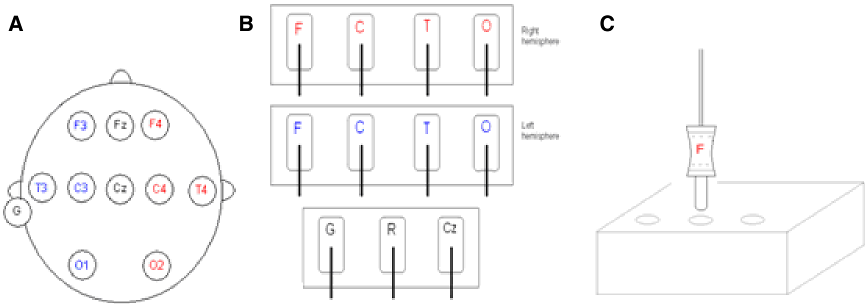

Figure 2 (A) International 10/20 system modified for infants was followed for application. (B) Labelling the positions on the electrode surfaces eased the application process. (C) Labelled electrode socket plugged into headbox.

- Cut small pieces of Mefix tape to help secure the electrodes (Fig. 3B).

Electrode Application

- Wash hands again, as per dedicated hand hygiene protocols, and open the incubator portholes for access. Using gloves is advisable.
- In our NICU, infants on CPAP have a hat in place to secure the CPAP mask. Cut the CPAP hat down the frontal midline region and lay it open. An assistant is required at this stage to hold the CPAP mask in place while electrode application is ongoing. In the intubated and ventilated infant, a CPAP hat is still applied, as it helps to protect and maintain the position of electrodes.
- Part the hair at the electrode site, and gently abrade the skin three to four times using a sterile cotton bud and a skin preparation gel such as Nuprep.
- Apply the electrodes to one side of the head and then the other, to reduce head turning and disruption to the infant (Fig. 3C).
- Position the electrodes so that all leads are directed towards the vertex (Fig. 3C). From here, they enter a stockinette, which helps minimise 50 Hertz interference.
- Cover each electrode with the precut Mefix tape to improve stability. This also prevents electrode bridging between adjacent electrodes (18).
- Resecure the CPAP hat using the Velcro strap and additional tape (Fig. 3D).
- Check all impedances before finishing the procedure. It is important that all electrodes have equal and low impedance, which tends to improve over time.

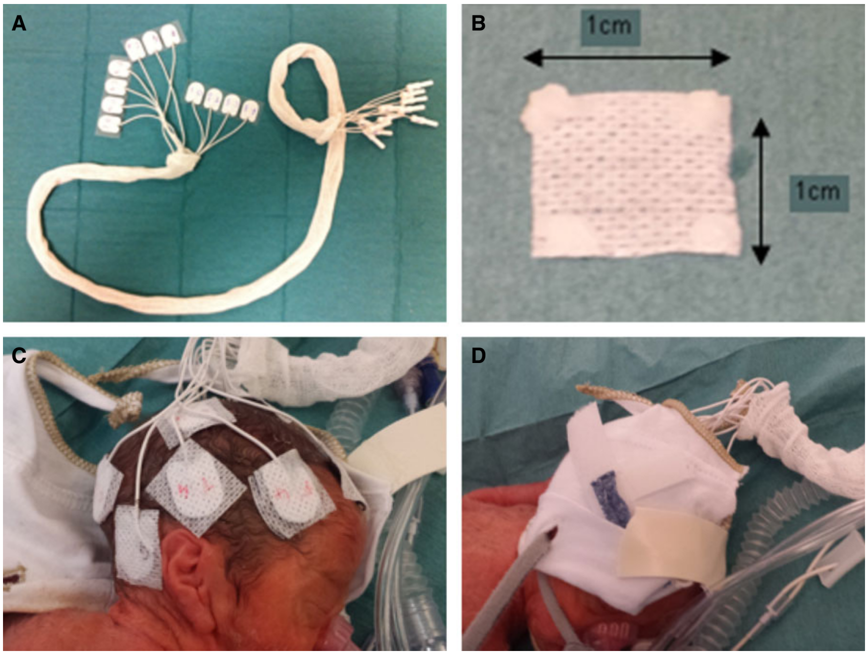

Figure 3 Key Steps of EEG Application (A) Prelabelled electrodes positioned inside the stockinette. (B) Electrode with tape and paste (C) Electrode positions on right hemisphere covered with tape. (D) Hat closed ready for recording.

- At the end of the recording, carefully remove the electrodes one by one. Slowly peel the tape from the corner in the direction of which the hair lies, to prevent pulling.

DISCUSSION

In this paper, a method for EEG electrode application has been described, which prioritises minimal handling of the very preterm infant. The key points include adequate preparation, infant-friendly electrodes and strict application and organisation of electrodes to maximise data quality. Our experience shows that the proposed method is safe, efficient and above all, mindful of infection control principles and policies within the NICU environment.

Benjamin Franklin once said that 'by failing to prepare, you are preparing to fail'. This quotation is as pertinent for EEG application as it is for all medical procedures. Time spent on preparation and organisation, prior to electrode application, is key and will minimise procedure duration, infant handling, risk of infection and optimise data quality. It is our belief that this technique can be completed faster and possibly more efficiently than prior techniques used for EEG monitoring.

Electrode prelabelling at both the sensor and plug end prevents any confusion for both application of the electrode and when tracking it back to the headbox of the computer. If a change in incubators is required, or relocation within the unit is indicated while still on long-term EEG monitoring, the leads can be disconnected from the head box, while remaining attached to the infant's scalp. The prelabelled electrodes can be quickly reinserted into the EEG headbox once the changeover is complete; thus, ensuring minimal EEG data is lost. The stockinette keeps the leads organised in the incubator, reducing entanglement with other equipment, such as ventilator tubing and infusion lines and also reducing 50 Hz artefact. The electrodes are applied to one side of the head at a time; therefore, the infant's head only needs to be turned once. The disposable surface electrodes are more infant friendly, but can be affected by humidity in the incubator. This is overcome by applying a small piece of Mefix tape, with conductive paste on the four corners, if required. In preterm infants, the skin is thin, and impedance is generally easy to reduce, again minimising handling of the infant and time spent in the incubator.

This procedure required minimal electrode maintenance. Due to the thinner skin layer, impedances were rarely a problem. The impedances were checked once a day for quality. Occasionally, impedances increased, and repositioning was needed, which was often when the infants were handled for emergency situations, which is unavoidable. Repositioning was straightforward and quick, achieved by opening the hat. Desiccation of the electrode gel was not a problem as the paste is water based and in most circumstances, infants are in a humid atmosphere within an incubator.

The EEG recording quality achieved with this method was generally excellent. Removing electrode and 50 Hz artefacts completely can sometimes prove impossible; therefore some artefacts did exist. Our protocol was to minimise the amount of electrode and 50 Hz artefacts to the best of our ability. However, these were no more than those routinely encountered with cup electrode recordings.

No skin abrasions, pressure marks, or other site issues were noted in any of the recordings using this method. We did not do a direct comparison with the cup electrode method; however, a previous study has shown that pressure marks can be seen on the scalp following EEG recordings with cup electrodes (11).

Cutting of the CPAP hat may not seem optimal but it dramatically reduces the duration of the EEG electrode application procedure, as it allows easier access to the scalp. Once the electrodes have been applied the hat is closed using the CPAP hat Velcro and additional tape. The CPAP hat has the added advantage of protecting and helping to keep the electrodes securely in place, while also making subsequent access to electrodes easier. This method does not compromise the secure nasal CPAP seal, however assistance is required to maintain the seal during electrode application. It is our experience that the use of additional tape keeps the hat securely fastened even during excessive head movement.

This paper recommends this technique for smaller preterm infants, but it is our belief that more mature term infants can also benefit. In our hospital we have changed previous practice to follow this technique for all infants, even for those infants who do not require CPAP. As most full-term infants have more hair, electrode application has proven more challenging when using the disposable, flat-surfaced, electrodes. More time is therefore required to ensure that the hair is parted properly at the point of electrode contact.

Existing literature describes different techniques for applying EEG electrodes. Schumacher et al. described a similar technique using disposable electrodes secured with a specially designed CPAP hat (15). Impedances, however, were much higher (target 40kΩ rather than <20kΩ). In our experience, preparing the electrode site carefully, and applying Mefix tape over the electrodes, ensures good impedances and consequently, the electrodes do not have to be frequently reapplied. Stjerna et al. used an EEG cap for preterm EEG monitoring and reported an effective technique of EEG application in preterm infants (16). An electrode cap array is undoubtedly an attractive option for infants, but a number of sizes are required for all gestational ages, and ideally, these hats need to be sterile and disposable. Most of the currently available EEG hats are for multiple use and cannot be sterilised and the only recommendations are to wash in warm soapy water (19). This is clearly not ideal for preterm infants in the NICU and poses a serious risk of infection in an already compromised population. Designing a hat that would facilitate both neonatal CPAP and EEG should be considered.

EEG cup electrodes are widely used in preterm infants and were our preferred option prior to the introduction of the technique described in this paper. In our experience, this new method is more efficient and requires less effort in maintaining recording quality. The adhesiveness of the disposable electrodes seemed to provide additional security to help maintain electrode position.

CONCLUSION

Preterm EEG application is challenging and requires a specific approach. The practical techniques described in this paper provide a simplified electrode application technique suitable for even extremely preterm infants. The basic principles, however, can be applied to both preterm and full-term infants.

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FINANCIAL DISCLOSURE

All authors have indicated that they have no financial relationships relevant to this article to disclose.

CONFLICT OF INTEREST

All authors have no conflict of interests to disclose.

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