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REVIEW/MISE AU POINT

EEG in the neonatal unit

L'EEG en néonatologie

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Summary The execution and interpretation of neonatal EEG adheres to strict and specific criteria related to this very early age. In preterm newborns, the dedicated healthcare staff needs to respect EEG indications and chronology of EEG recordings in order to diagnose and manage various pathologies, and use EEG in addition to cerebral imaging. EEG analysis focuses on a global vision of the recording according to the neonate's state of alertness and various age-related patterns. Monitoring of continuous conventional EEG and simplified EEG signal processing can help screen for seizures and monitor the effect of antiepileptic treatment, as well as appreciating changes in EEG background activity, for diagnostic and prognostic purposes. EEG reports should be highly explanatory to meet the expectations of the physician's clinical request.

MOTS CLÉS
Nouveau-né ;
Prématuré ;
Traitement du signal ;
EEG ;
Pointes positives rolandiques

Résumé La réalisation et l'interprétation de l'EEG néonatal répondent à des critères stricts et spécifiques à cet âge. Le respect des indications et de la chronologie des enregistrements par un personnel dédié chez le prématuré en particulier permet le diagnostic et la prise en charge de pathologies variées en complément de l'imagerie. L'analyse du tracé porte à la fois sur une vision globale du tracé en fonction de la vigilance et sur les différents patterns liés à l'âge. Le monitoring de l'EEG conventionnel et du signal EEG simplifié en continu permettent le dépistage et le suivi sous traitement des crises ainsi que l'appréciation des modifications du tracé de fond à visée diagnostique et pronostique. Les comptes—rendus s'intègrent dans une demande clinique complète et doivent être très explicites.

Abbreviations: NICU, neonatal intensive care unit; PRSW, positive rolandic sharp waves; GA, gestational age; CA, conceptional age.

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Summary of guidelines

Technical recommendations

The technical recommendations are:

- an electroencephalogram is a useful, reproducible and non-invasive tool for brain exploration that can be performed at the patient's bedside. EEG is a highly relevant and predictive test for establishing an early diagnosis in newborns;
- a detailed request for an EEG is mandatory including clear clinical motives as well as circumstances of the pregnancy, gestational age (at birth) and conceptional age (i.e. actual) both calculated from the first day of the mother's last periods, and a record of all treatments administered to the baby;
- in order to be informative, the neonatal EEG must record the newborn's sleep;
- its diagnostic and prognostic value depends on when the test is performed and the duration of the recording;
- to limit wrongly pejorative evaluations from EEG performed too early after birth, indications for EEG recordings performed before 10, 24 or even 48 hours of life are restricted to pathological situations and the prognostic evaluation will need to be validated by other tests;
- the ideal duration of the recording is that which is necessary in order to obtain a full sleep cycle, i.e. 45 to 65 *interpretable* minutes;
- neonatal EEG is a polygraphic examination and must include, besides the EEG, at least ECG and respiratory signal recordings;
- at least eight active surface electrodes are positioned according to the international 10/20 system and the set-up is adapted to the neonate head circumference: Fp1, Fp2, C3, C4, T3, T4, O1, O2;
- to understand the artifacts and detect cardiorespiratory events (immaturity of autonomous functions in newborns), an ECG and at least one respiratory sensor are the minimum required;
- use of volatile substances (e.g. ether, collodion, acetone) for improving the electrodes' impedance, attaching the electrodes and/or cleaning the scalp after the EEG recording is no longer recommended due to their toxicity and inflammable nature (DMT 127 2011);
- the impedance of electrodes, especially for reference and ground electrodes, must be inferior to 10 kΩ;
- in newborns, because of low voltage EEG signal, especially in premature babies, the norms require that the EEG background noise for a 5 kΩ input resistance be lower than 1.5 μV in order to validate electrocerebral inactivity;
- because of modern computerized equipment, it is possible to modulate the EEG display; however, to be able to compare it to normal patterns or pathological figures of reference, it is recommended that the EEG be visualized in a display window respecting the calibration of the amplitude (10 μV/mm or 100 μV/cm), with an EEG bandwidth between 0.16 and 70 Hz;
- regarding the montages used locally, it is recommended to program at least two montages: longitudinal montage (Fp2-T4;T4-O2;Fp2-C4;C4-O2; Fp1-C3;C3-O1; Fp1-T3;T3-O1), transverse montage (Fp2-T4;FP1-T3;T4-C4; C4-C3;C3-T3; T4-O2;O2-O1;O1-T3, and when CZ is used: T4-CZ;CZ-T3;C4-CZ et CZ-C3);
- the baby's reactivity to electrode placement will be carefully noted, as well as the exact dosage, in absolute value (μg/kg/h), of the ongoing medical treatments;
- during data acquisition, the technicians should constantly monitor the newborn and note on the recording all clinical, technical or EEG events;
- it is recommended to record all states of alertness normally present at the baby's conceptional age at the time of the EEG procedure;
- technicians must be trained to recognize all states of alertness in newborns;
- technicians must be trained to recognize clinical and EEG symptoms of seizures in newborns;
- interpreting an EEG in newborns requires specific training and regular practice.

Interpretation of a neonatal EEG

The interpretation of a neonatal EEG must take into account:

- the conditions of the recording: the child's parameters (age, vital signs, medication); technical setting (quality controls); baby's behavior when positioning the electrodes and during the entire recording;
- global analysis of the background activity (lability/states of alertness, amplitude, reactivity);
- analysis of each state of alertness (e.g. waveform types, morphology and spatiotemporal organization of the physiological figures, symmetry and synchronicity);
- analysis of pathological figures (changes in EEG figures, abnormal superimposed figures, seizures, cardiac or respiratory events);
- the analysis of a neonatal EEG should take into account the child's age (quality of the maturation) or, if the age is imprecise, help determine it;
- the analysis of a neonatal EEG should be compared with the objective of the procedure: does the examination answer the question asked by the requesting clinician?
- the simplified amplitude-integrated EEG (a-EEG) modifies the EEG signal and thus should not replace conventional EEG when the latter is available;
- a-EEG requires, just like conventional EEG, quality technical prerequisites (control of raw EEG data);
- a-EEG requires, just like conventional EEG, specific training and regular practice.
- neonatal EEG indications should respect current guidelines.

Full-length guidelines: neonatal EEG at the laboratory and in the NICU

These guidelines are applicable from the conceptional age of 25 weeks up to 50 weeks of amenorrhea, i.e. from very preterm neonate to the 2-month newborn.

Introduction

EEG is a reproducible, non-invasive brain exploration test that can be performed at the patient's bedside. It has a relevant diagnostic and prognostic value in neonates. This evaluation of the brain function is complementary to the clinical evaluation (often limited within the setting of the intensive care unit, in a sedated newborn or one at risk of seizures with little or no symptoms) and morphological data obtained via brain imaging techniques.

The 2-month limit can be explained by technical specificities and mostly the important changes in electrogenesis at that age, especially in terms of sleep rhythms.

Preparing for the EEG

EEG request

An explicit EEG request is mandatory; this should include a clear clinical motive, circumstances of the pregnancy, GA and CA, both calculated from the 1st day of the mother's last menstrual periods (LMP) as well as a list and indications for all treatments administered to the baby.

Successive EEG requests for the same patient will be updated according to the clinical evolution.

Test organization

In order to be informative, the EEG must record the child's sleep cycle (decreasing artifacts triggered by the baby's agitated or crying state, and evaluating the maturation of the consciousness state). It is essential to prepare the test several days beforehand. Information will be transmitted to the requesting service and to parents by phone and/or mail; the authorization to record the test on video will also be signed by the family (*should the test be used for educational purposes*).

In neonates, the presence of parents is preferable at least during the beginning of the set-up when electrodes are positioned in order to reassure patients and their family. To easily obtain sleep, the recording is specifically programmed at the end of an alertness period, at a distance from an eventual administration of caffeine. The test requires a quiet and silent environment: the temperature will be set between 19 and 21 °C, and the baby's comfort toys/blanket are also necessary. Newborns will be breastfed or bottle-fed right before or during the electrode set-up so that they are not awakened later by hunger. No drug will be administered to facilitate sleep in order to avoid interference with electrogenesis.

Time and duration of the examination

The EEG can be performed any time after the baby's birth, yet its diagnostic and prognostic value depends on the moment it is performed and the duration of the recording.

To limit false negative EEG evaluations when the test is performed too early after birth, EEG indications before 10 hours of life or even 20 or 48 hours of life, are restricted to pathological situations. In such early recordings, prognostic value is limited and the reliability of EEG will increase over time.

The issue of time factor is not however relevant when looking for seizures (diagnostic EEG).

The ideal EEG duration is that which is necessary for obtaining one sleep cycle, i.e. 45 to 60 *interpretable* minutes.

Clinical situation requirements might imply changes in the duration and modalities of the EEG recording: the latter might be extended for a longer period of time and EEG monitoring might be justified (for example, to treat confirmed seizures or evaluate their frequency, duration and impact of treatments).

Neonatal EEG recording techniques

Generalities

Regardless of the recording site (laboratory or neonatal intensive care unit NICU), the recording should disrupt as little as possible the behavior and usual nursing care of the newborn.

The data acquisition device should be positioned as close as possible to the child so that the technician or well-trained nurse can observe and note the newborn's behavior during the EEG, even during simultaneous video recording.

The following data must also be recorded, especially in the NICU: temperature; type of mechanical ventilation as well as its nature; drug dosage and administration time, especially sedatives and antiepileptic drugs that alter EEG activity. It is also recommended to note the treatments received by the new mother (C-section under general anesthesia for example).

At minimum, neonatal EEG recording should be associated with ECG and respiratory recordings.

Eye movements, chin EMG tone and body movements might also be recorded if necessary. At best, video-EEG will be proposed to validate, analyze and/or correlate abnormal movements and seizures to EEG epileptiform discharges or locate the origin of artifacts.

Material and techniques

In routine clinical practice, the following is recommended:

- for EEG, either disposable, pre-gelled, self-adhesive, flat cup electrodes, or silver cup electrodes maintained by a conductive paste and an elastic net bandage like Surgifix® (avoiding the use of needles or hook electrodes);
- for ECG, disposable pre-gelled electrodes;
- for respiratory signal recordings, either a strain gauge or piezoelectric quartz crystal (PQC).

Technical characteristics of the different recorded parameters in neonates are listed in Table 1 and in the references [3,5,12].

Scalp electrodes. At least 8 active surface electrodes are positioned according to the international 10/20 system adapted to the newborn's head circumference: Fp1, Fp2, C3, C4, T3, T4, O1, O2. In premature babies, it is useful to place an additional electrode in Cz (some teams use three electrodes on the Fz-Cz-Pz midline when the head circumference allows it), with a midfrontal reference electrode. The ground electrode is often the reference electrode, or these can be two distinct electrodes. The high electrical resistance of the skin in newborns requires the use of a soft abrasive gel to prepare the site of the electrode, and

Table 1 Recording techniques and artifact identification in very preterm newborns.

Parameters	Transducers	Electrode placement	Gain	Time constant (minimum) (s)	Filters	
					High-pass (Hz)	Low-pass (Hz)
EEG	Silver-silver cups Secured by: surgifix flexible helmet conducting adhesive paste (do not use collodion)	Montages: antero-posterior or transverse (minimum six leads)	10 μV/mm	0.3	0.5	30
	Preborn electrodes Disposable ECG electrodes Disposable needle electrodes[a]	Adapted from 10—20 system, always including: Fp2,C4,T4,02$_t$Fpl, C3, T3, 01	Adjustable			
ECG	Disposable ECG electrodes Silver—silver cups	Chest (precordial) or limbs	Adjustable	0.1	1.5	30
Eye movements	Piezo crystal Silver—silver cups	Upper eyelid	Adjustable	0.1	1.5	70
		Slightly lateral to the canthi		0.3	0.5	30
EMG Chin Other muscles	Surface electrodes: silver—silver cups others	Active: on the chin muscle reference: on the mandible Adjustable	Adjustable	0.1	1.5	30—70
Respiration	Strain gauges Thoracic impedance Piezo crystal	2 cm above umbilicus Lower thorax	Adjustable	1	0.15	15
	Thermocouples Thermistors	Nasobuccal (airflow)	Adjustable	1	0.15	15
Body movements	Piezo crystals Charge-sensitive mattress	On the limbs Under the body	Adjustable	0.1	1.5	70
SaO^2	Specific transducers	Hand or foot		DC amplification — parallel recording — manually check the values		

According to Walls et al. [12].
EEG: electroencephalogram; EMG: electromyogram.
[a] Needle electrodes are contraindicated in the event of coagulation abnormalities or hematoma.

a conductive paste is then applied. According to the newborn's head size and location of abnormalities, reference electrodes can also be positioned on the ears (bi-auricular reference).

Note: using volatile agents (e.g. ether, collodion, acetone) to improve the electrodes' impedance, to better fix them and/or clean the baby's scalp after the recording, is now formally forbidden due to the toxicity and inflammable nature of these agents. Oil-based creams (e.g. almond oil, baby oil) must be used.

Montages. Even if montages used during data acquisition and EEG reading are often specific to each team, it is highly recommended — and can easily be done with today's automated devices — to program at least two montages common to all teams to facilitate cross-reference EEG reading:

- a longitudinal montage (Fp2-T4; T4-O2; Fp2-C4; C4-O2; Fp1-C3; C3-O1; Fp1-T3; T3-O1), to correctly visualize the temporal or rolandic phase-reversed figures (PRSW);

- a transverse montage (Fp2-T4; Fp1-T3; T4-C4; C4-C3; C3-T3; and T4-O2; O2-O1; O1-T3 or, if Cz is used, T4-C4; C4-Cz; Cz-C3; C3-T3).

Neonatal EEG is necessarily a multiple-channel recording: to understand artifacts and detect cardiorespiratory events (autonomic nervous system activity immaturity in newborns), the minimum required is an ECG channel and at least one respiratory sensor. Additional sensors, such as EMG electrodes, actimeter or piezoelectric quartz devices can evaluate the neonate's movements. Several respiratory sensors (oronasal thermistor) and blood oxygen saturation sensors (pulse oximeters) can help appreciate the severity of cardiorespiratory events that could alter the brain electrogenesis.

If the sleep-wakefulness cycle must be evaluated, it is essential to add 2 electrodes to record eye movements and one chin EMG electrode.

Quality controls. Electrode impedances, and especially impedance of the ground and reference electrodes must be < 10 kΩ. This quality control is essential; it is recommended to perform the verification test at the beginning and end of the recording and for each unexplained alteration of the EEG recordings when verifying the electrodes in place. These quality controls must be available during the EEG recording analysis.

In case of focalized low voltage, the absence of an electrical bridge must be verified, e.g. insufficient distance between the electrodes or conductive paste leaks from one electrode to the next.

Finally, standards require that the EEG device background noise should be less than 1.5 μV for an input resistance of 5 kΩ (validation of electrocerebral inactivity).

Recording display. The recording can be analog or digital; technical requirements for data collection are similar in both techniques. The quality but above all the reliability of the digital recording depends on the digitization process and characteristics of the signals to be recorded.

Screen dimensions vary from one EEG device to the next. It is recommended that the EEG recording be visualized in a display window respecting the amplitude calibration (10 μV/mm or 100 μV/cm) and scrolling speed (15 mm/second), with a visualization bandwidth between 0.16 and 70 Hz.

Recording process. The newborn's reaction to the placement of the electrodes will be carefully noted, along with the exact dosage in absolute value (μg/kg/h) of the ongoing administered medications.

Later on, at the beginning of the recording and without any filter, make sure that no electrical noise interferes with the unipolar reference montage (i.e. where all active electrodes are compared to the reference electrode). After this verification, the 50 Hz filter can be useful, even necessary in the intensive care unit.

During data acquisition, technicians should constantly observe the baby and note on the recording: body movements, facial expressions, eye movements, apneas, bradycardia, SaO_2 levels, noises and nursing care administered. As experienced observers, they will also be able to detect abnormal figures and eliminate artifacts. Tactile stimulations will be done at the end of the recording. This is the proper way to check reactivity of the recording. Environment-related noise stimuli will be noted.

Reactivity. External stimuli can trigger changes on the EEG; for example loud noise or high-intensity light stimuli can attenuate the overall brain activity. These reactions last a few seconds and can be interpreted like the Moro reflex.

In extremely preterm neonates, flashing light stimuli can sometimes trigger visual evoked potentials, which, because of their great amplitude at that age, become very noticeable on the EEG. Intermittent photic stimulation with flashing lights at a frequency < 2 Hz yields the same reaction. This flashing light reactivity disappears when premature babies get older, probably due to the lower amplitude of the evoked potentials and a greater background activity in the occipital regions during this baby's brain development stage. In neonates, the reaction when opening the eyes is not identifiable. This reaction, observed in children and in adults, does not become visible before the age of 2 to 6 months.

During the EEG It is essential to record all states of alertness normally present at the newborn's adjusted age; technicians must be trained in recognizing these states of alertness in newborns.

Specificities of EEG in the neonatal intensive care unit (NICU)

Limits of EEG indications. Sometimes, in newborns that are in an unstable autonomic state (very preterm neonates for example), the NICU team can refuse the EEG request if they deem that the baby is too fragile. However, the EEG is essential to understand the origin of the unstable autonomic state while being extremely attentive to respecting the cardiorespiratory constraints when positioning the electrodes; the technician should be trained to this approach and take into account the acceptability of the test by the newborn in the framework of developmental care.

Safety and recording conditions. All equipment in contact with the newborn must be sterile or disposable. It must be prepared in advance in order to reduce the set-up time, and the technician in charge of the recording must take rigorous precautions regarding keeping everything under sterile conditions.

During neonatal EEG recording, electrical disturbances can occur, especially when using an incubator, heating mattress, internal catheters and/or various invasive or non-invasive ventilation modalities (e.g. infant flow nCPAP, high frequency ventilation). The technician must learn to recognize and manage these potentially dangerous situations that could trigger artifact, which might prevent the proper reading of the EEG.

Any drug interaction, especially potential bolus administration of morphine, will be looked for and reported, as well as the delay in their administration with regards to the EEG recording.

The NICU environment must be respectful of the EEG test during electrode positioning and recording by avoiding non-urgent care or going around the newborn's bed during the test.

Interpretation of neonatal EEG

Interpretation of neonatal EEG requires specific training and regular practice to learn to recognize the physiological

markers of electrogenesis maturation and its unusual or pathological aspects as described in the literature [1,4,10].

This interpretation must include recording conditions and electrogenesis analysis.

Recording conditions
The recording conditions are:

- the newborn's environment (i.e. spontaneous or assisted ventilation, temperature, therapeutics: psychotropic drugs, sedative drug, analgesics, and antiepileptic drugs);
- the baby's behavior when positioning the electrodes (reactivity) and during the recording (eye and body movements, eyes open or closed);
- technical conditions in case of digital EEG: verification of the EEG without any filters (specially the 50 Hz one) reference acquisition montage; the precise position of the reference electrode must also be noted.

Electrogenesis analysis
Global analysis of the background activity. The global analysis of the background activity consist of:

- lability: quick reading of the recording at slow speed (2.5 mm/s or less), in order to visualize one or several minutes on the display screen, to detect the different alertness states (behavioral and/or EEG-related sleep stages);
- global amplitude;
- clinical and or electrical reaction.

Analysis of each alertness state differentiated on the EEG. The analysis of each alertness state differentiated on the EEG consist of:

- continuous or discontinuous tracing/''tracé alternant'' (with indications on minimum and maximum durations of the bursts, and maximum duration of inter-bursts intervals);
- physiological figures: frequency, morphology, amplitude and spatial organization;
- symmetric or not, continuous or not;
- synchronous or not, continuous or not.

Pathological figures. The pathological figures consit of:

- epileptiform discharges: morphology, location, duration:
  - are they correlated with the clinical observation/simultaneous video recording?
  - when anticonvulsive medications are administered, note the name, modalities and time of administration, as well as dosage in absolute value and eventual drug-induced changes on the EEG;
- abnormal superimposed figures: note their morphology, duration, amplitude, location, frequency (number per minute), as well as their nature, isolated or repeated in brief sequences.

Cardiac and/or respiratory events during the recording.

- Are cardiac and/or respiratory events synchronous or not with similar figures on EEG derivations ? (cardiac and/or respiratory artifacts who can sometimes imitate a critical sequence.
- Is the baby presenting with apnea without or not secondary bradycardia ?

Conclusions: which questions can be answered?
Which questions can be answered?

- is there a temporal organization? Is the quality of the EEG good enough to define this?
- is there a spatial organization? Is the quality of the EEG good enough to define this?
- if the baby's gestational and conceptional ages are known, is the EEG in accordance with the defined age?
- if the gestational and conceptional ages are unknown, is the EEG able to define them?
- if abnormalities are present on the recording, do they have a diagnostic and/or prognostic relevance?
- is it necessary to perform another follow-up EEG test? If so, what should the delay be between both tests?

Specific protocols

In some situations, a neonatal EEG is requested as an emergency and should be prolonged for several hours or several days (suspicion of seizures and/or hypoxic-ischemic encephalopathy). Placement of electrodes is reinforced by an adhesive paste covered by a gauze pad under a Surgifix® net bandage.

When the neurophysiologist experienced in neonatal EEG is unavailable, some signal processing techniques described below can be used under certain conditions.

Amplitude-integrated EEG (a-EEG) via *cerebral function monitor* (CFM)
This is a method centered on the analysis of EEG activity amplitude [7]. The latter is collected continuously at the children's bedside through 2 central electrodes (C3, C4), discarding signals with frequency < 2 Hz and frequency > 15 Hz, in order to avoid main artifacts caused by movements and extra-cerebral electrical activity. After signal rectification (i.e. all signals on the negative side) and smoothing, this trending modality uses a semi-logarithmic scale, to correct the amplitude differences of the various rhythms according to their frequency. Finally, the processed signals are compressed at the speed of 6 cm/hour i.e. 10 min per centimeter (or 1 mm per minute) and represented as a band permitting a visual analysis of the following elements (automatic frequency analysis, presented as EEG power percentage is possible):

- mean amplitude of the lower margin (usually > 5 μV): the a-EEG is considered discontinuous if the lower margin is inferior to 5 μV;
- mean amplitude of the upper margin (usually > 10 μV);
- lower margin variations and their morphology (physiological liability, cycling of alertness states or, conversely, sudden spiky rises into the lower margin suggesting a seizure) [2]. Thus, the emergence of a sleep-wake cycling pattern is the factor best correlated with the newborn's

conceptional age and seems to represent the best criterion for brain maturation [11];
- morphology and density of the upper margin (suppression-burst aspect of the a-EGG, this term is restricted solely to the a-EEG).

This signal processing technique, created in 1962 by adult ICU teams to evaluate brain anoxia, was developed and validated by several NICU teams for the monitoring of brain maturation in premature babies, for the early diagnostic and prognostic assessment of hypoxic-ischemic encephalopathy in term newborns, as well as detecting neonatal seizures [6,8].

The evaluation of amplitude-integrated EEG ''a-EEG'' versus conventional EEG ''c-EEG'' is recent and reports that c-EEG, preferably coupled with video recording, remains the ''gold standard'': as a matter of fact, by only focusing on the amplitude of selected and modified EEG signals, with no refined artifacts elimination, a-EEG does not allow the study of physiological figures and misses about 30% of epileptiform discharges, because of its insufficient spatial and frequency coverage; however its sensitivity increases with the number of scalp electrodes. Finally, the morphological analysis, essential to identify seizures, slow waves and artifacts, can only be performed on the source EEG, sole witness to the quality of raw data acquisition.

This technique, which can quickly be set-up in an intensive care unit, can be used if c-EEG is not available (outside of routine working hours or in the absence of on-call technicians). It can be used in all newborns at risk for neurological impairment. *It can detect 100% of status epilepticus cases (sometimes not clinically detected at night, because of darkness)*. Furthermore, verifying the absence of epileptiform discharges in the central regions avoids useless treatments during suspicious paroxysmal events.

The interpretation of the a-EEG band can only be validated after having been compared to the source EEG for each of the relevant elements. A lower margin may appear normal (> 5 μV) if some artifacts (ECG for example) increase the mean amplitude of the signals whereas the background activity is of very low voltage or even inactive. It is not recommended to use this technique without comparing it to the source EEG, which can help refine the nature of any changes on the curve. Furthermore, teams must be trained to recognize and manage the artifacts. A conventional EEG should be done as soon as possible when there is discordance between the a-EEG and the clinical situation.

The simultaneous use of a conventional EEG initiated by the neurophysiology team coupled with a-EEG display window accessible 24/7 to the NICU team has the advantage of quickly managing emergencies while yielding a more complete analysis — performed by an experienced neurophysiologist — of the data collected outside routine working hours. Furthermore, electrode positioning can be adapted when a region of interest has been previously identified (stroke for example).

Finally, this technique is sometimes used outside of the neonatal period, but these indications have not yet been validated.

Density spectral array (DSA)
The visual reading of EEG signals can be replaced by a density analysis of each of its rhythmic activity positioned on a scale of 0 to 30 Hz (alpha, theta, delta) according to time, the density of each rhythmic activity being displayed by a color scale (from the colder color — blue — for the less frequent rhythms, to the warmer one — red — for the dominant rhythms). It can also compute the *spectral edge frequency*, defined as the frequency below which 95% of the power in the EEG is located at a defined ''t'' time.

This technique, which can either target a region of interest, or be read in double-display next to each EEG derivation, has the advantage of not truncating or altering EEG signals, and showing all EEG components, including some physiological rhythmic activity. In this technique, artifact identification is also based on the visual analysis of the EEG signal morphology. This method, developed by neurophysiologists, without any distortion of the source signals, is preferable when NICU teams can be trained to use it.

Other specific protocols
Other protocols, such as the discontinuity index and signal power are sometimes used, but mostly in clinical research settings.

Indications

Full-term newborn

There is no systematic EEG indication. However EEG is relevant in the following clinical situations.

Abnormal neurological signs
For example, in cases of: perinatal asphyxia; neurological distress; hypotonia; neurovegetative symptoms; abnormal movements; behavioral disorders.
Diagnostic relevance of the EEG. Diagnostic relevance of the EEG, for example:

- identifying seizures;
- looking for focal abnormalities (hemorrhage, stroke, abscess);
- recognizing the telltale aspects of some etiologies (e.g. metabolic diseases, herpes simplex encephalitis).

Prognostic relevance. This is based on:

- the organization of the background activity and sleep structure;
- etiological clues provided by the EEG.

When should the EEG be performed?. When should the EEG be performed?

- from the appearance of first symptoms, preferably coupled with video;
- the test should be repeated every 4 to 6 days, until the EEG recording is normal or stabilized;

- the test can be repeated even more frequently according to clinical symptoms or EEG results.

Seizures (convulsive or non-convulsive)
For seizures, long-term video-EEG is recommended
Diagnostic relevance.
Positive diagnosis. The positive diagnosis are:

- epileptic seizure: discharge of rhythmic elements for at least 10 seconds, with or without clinical symptoms;
- status epilepticus, clusters of seizures, continuous or prolonged seizures, prolonged seizures.

Differential diagnosis. With regards to non-epileptic paroxysmal events, not to be treated
Etiological orientation. When faced with characteristic ictal or interictal aspects.
Prognostic relevance. Based on signs pertaining to the severity of the condition:

- electroclinical dissociation of the seizures;
- frequency of seizures;
- duration of the seizure period;
- interictal abnormalities.

Relevance to the newborn follow-up. To evaluate response to treatment.
When should the EEG be performed?. The first EEG should be performed from the time of suspicion of seizure, if possible before administering any antiepileptic and/or sedative medication.
Long-term or even continuous recording can be justified while implementing the medical treatment.
Repeat EEG tests will depend on the clinical evolution and results of the first EEG.

Hypoxic-ischemic encephalopathy (HIE)
Diagnostic relevance. EEG can help identify the unusual aspects of the recording to avoid mistaking HIE for another etiology.
Prognostic relevance. Based on assessing the severity level:

- distinction between normal, pathological (inactive, paroxysmal, ''pauvre plus thêta'') or ''intermediate'' (discontinuous, fast hyperactive) [9];
- normalization delay.

Note: severe abnormalities, if recorded before the twelfth hour of life, can quickly be reversible; in that case, the EEG does not yield a prognostic contribution. However, these abnormalities can lead to use of early hypothermia after hypoxic-ischemic injury.
When should the EEG be performed?. It is recommended to do the first EEG between 12 and 48 hours of life (long-term or even continuous EEG), then control EEGs at D4 and D8, even earlier according to the clinical symptoms and results of the first EEG. Further control tests might be performed down the line according to the electroclinical evolution of the newborn.

Preterm newborn

Indications according to symptoms
EEG is mandatory in case of neurological risk factors or signs of neurological distress:

- in case of neurological abnormalities, especially seizures, the indications and relevance are the same as for full-term newborns;
- in the absence of symptoms or risk factors, EEG can be useful to determine the preterm neonate's maturation level.

Indications according to the gestational age (GA)
The indications according to the gestational age (GA) consist of:

- GA $\leq$ 28 weeks of amenorrhea: EEG monitoring is systematic;
- GA comprised between 29 to 33 weeks of amenorrhea: EEG is recommended in the first weeks of life.

Diagnostic relevance
The diagnostic relevance consist of:

- evaluating the background activity;
- looking for superimposed abnormalities and seizures;
- contributing to diagnosis of periventricular leukomalacia due to the characteristic EEG figures (PRSW occurring before brain damage confirmed on imaging).

Prognostic relevance
The prognostic relevance consist of:

- organization and physiological maturation of the EEG recording;
- evolution of EEG abnormalities (frequency and lingering presence of PRSW, correlated to the severity and extent of periventricular white matter injury).

When should the EEG be performed?

$\leq$ 28 GA	29—33 GA without risk factors[a]	29—33 GA with risk factors[a]	> 33 GA with risk factors[a]
D2—D3		D1—D3	
D7—D8	1st week	D7—D8 (32 CA)	1st week
31—32 CA		36 CA	
36 CA			

EEG: electroencephalogram; GA: gestational age; CA: conceptional age.
[a] Risk factors.

EEG should be performed when:

- acute fetal distress;
- infection:
  - prolonged rupture of membranes,
  - chorioamnionitis,
  - validated maternal-fetal infection;

- ischemia:
  - hemodynamic disorders,
  - acute low blood pressure,
  - hypovolemia;
- twin-to-twin transfusion syndrome;
- surviving twin when the other died in utero;
- necrotizing enterocolitis;
- abnormal or suspect ultrasound scans.

This chronology varies according to the clinical evolution. If the recording is abnormal under sedation, a control EEG will be performed after treatment withdrawal.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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