Neurophysiologie Clinique/Clinical Neurophysiology (2015) 45, 65—74

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ORIGINAL ARTICLE/ARTICLE ORIGINAL

EEG in children, in the laboratory or at the patient's bedside

L'EEG de l'enfant, au laboratoire ou au lit

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Received 7 November 2014; accepted 9 November 2014
Available online 15 January 2015

KEYWORDS
Guidelines;
Infant;
Child;
Adolescent;
EEG recording techniques;
EEG indications;
Childhood epilepsy

Summary In pediatrics, EEG recordings are performed on patients from the neonatal period up to young adults. This means adapting techniques to many different conditions, concerning not only the patient's age, the need for asepsis and the patient's behavior, but also the environment (e.g. in the laboratory, at the patient's bedside, or in the neonatal intensive care unit [NICU]). Technical requirements depend on age, indication and the type of examination; in infancy, there should be a minimum of 12 EEG electrodes, ECG and respiration recording. In epileptology, surface EMG is also necessary to characterize the type of seizures and refine the diagnosis of epilepsy syndrome, on which physicians will base their treatment choice. The role of the EEG technician is essential because the quality of the recording, its analysis and conclusion will depend on the quality of the technical set-up and the interaction with the child. Sleep is a systematic part of the study up to the age of 5 years for several reasons: sleep EEG yields information on brain maturation; the EEG tracing during wakefulness can contain too many artefacts; and some grapho-elements, key to the diagnosis, only appear during sleep. The time of the examination must be chosen according to the child's usual nap times, possibly after sleep deprivation. Grapho-elements and spatio-temporal organization of the EEG vary with age, and

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http://dx.doi.org/10.1016/j.neucli.2014.11.008
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normal variants and unusual aspects are quite wide for any given age; this is why a physician experienced in pediatric EEG should perform the interpretation. This chapter concerns EEG performed in infants, children and adolescents, its technical aspects according to age and indications (general pediatrics, emergency, epilepsy).
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MOTS CLÉS
Recommandations ;
Nourrisson ;
Enfant ;
Adolescent ;
Techniques d'enregistrement EEG ;
Indications de l'EEG ;
Épilepsie de l'enfant

Résumé Réaliser un EEG en pédiatrie, c'est enregistrer des enfants dès la période néonatale jusqu'à des jeunes adultes. Cela veut dire s'adapter à des conditions d'examen très différentes, d'âge mais aussi d'environnement (au laboratoire, au lit du patient, en unité de soins intensifs), d'asepsie et de comportement. Les techniques d'installation dépendent de l'âge, de l'indication et du type d'examen ; le minimum chez le nourrisson étant de 12 électrodes EEG, un ECG et la respiration. En épileptologie, l'enregistrement de l'EMG de surface est indispensable pour caractériser le type de crises et le diagnostic de syndrome épileptique dont va dépendre le choix du traitement. Le rôle du technicien est primordial car de la qualité de l'installation et de l'attention qu'il va porter sur l'enfant vont dépendre de la qualité de l'enregistrement, l'analyse et la conclusion de l'examen. Le sommeil est systématique jusqu'à l'âge de 5 ans : le tracé de veille peut être trop artéfacté et certains grapho-éléments clés du diagnostic n'apparaissent qu'au cours du sommeil. L'heure de l'examen doit être choisie en fonction des habitudes de l'enfant pour obtenir un sommeil de sieste, parfois après privation. Les grapho-éléments et l'organisation spatio-temporelle de l'EEG évoluent avec l'âge et les limites de l'« inhabituel » sont larges pour un âge donné ; c'est pourquoi l'interprétation doit être réalisée par un médecin expérimenté pour l'EEG pédiatrique. Ce chapitre concerne les EEG réalisés chez les nourrissons, les enfants et les adolescents, les aspects techniques en fonction de l'âge et des indications (pédiatrie générale, urgences, épilepsie).
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Abbreviations

CSWS	continuous spike-waves during slow-wave sleep
DSA	density spectral array
EEG	electroencephalogram
EMG	electromyogram
HV	hyperventilation
ICU	intensive care unit
ILAE	International League Against Epilepsy
IPS	intermittent photic stimulation
LTVER	long-term video-EEG recording
nREM	non-rapid eye movement sleep
TBI	traumatic brain injury

Summary of guidelines

Techniques

Pediatric EEG should be performed by an experimented technician, in an adapted environment.

Pediatric EEG interpretation should be performed by a physician experienced in pediatric EEG.

The request for pediatric EEG should be thoroughly detailed and the indication for the EEG clearly listed: e.g. past medical history, disease history, description of eventual suspicious symptoms and treatment history. When a request is not in compliance with the EEG indications, the neurophysiologist may object to the request (e.g.: traumatic brain injury without loss of consciousness, headaches, vasovagal syncope — see EEG indications below).

According to the available clinical data, the neurophysiologist will specifically adapt the technical methodology used (i.e. additional polygraphic parameters; extending the hyperventilation activation maneuver; sleep recording in children above the age of 5 years).

The EEG daytime nap recording should include at least light and deep slow-wave sleep, a period of wakefulness as well as hyperventilation and IPS (according to the child's age).

Before the age of 5 years, EEG sleep recording is recommended not only because awake EEG is often disrupted by many artifacts but also because of further maturational criteria and appearance of eventual abnormalities only during slow-wave sleep.

After the age of 5 years, if clinically necessary, a daytime nap recording can be programmed after sleep deprivation.

Any long-term ''day—night'' recording requires the presence of at least one of the parents.

The technical set-up uses the international 10/20 system.

ECG and respiration recordings are mandatory, since they can screen for potential cardiac arrhythmias or respiratory rhythm disorders in newborns or infants, and help with the interpretation of artifacts, related or not to breathing movements, especially at the patient's bedside and in the absence of simultaneous video recording.

After the age of 5 years, the number of electrodes to be used should be similar to adult EEG.

Before the age of 5 years (except for the neonatal period), the number of electrodes (at least 12 electrodes: Fp1, Fp2, T3, T4, T5, T6, C3, C4, O1, O2, Cz, and one reference electrode) is adapted to the head size and the clinical indication.

Bridge electrodes or silver chloride disc electrodes can be used.

According to the head circumference, electrodes are fixed onto a head cap or inserted into a soft cap. Regardless of the child's age, cup electrodes can be maintained by conductive paste and a gauze pad, held by a light net bandage.

The examination should include the following stimulation procedures: eye opening and closure; hyperventilation; and intermittent photic stimulation.

After the age of 5 years, the recording of the EEG is comparable to that performed in adults, with a wakefulness recording for at least 20 minutes; sleep recording can be performed according to the clinical indication or the result from the wakefulness EEG.

When the technical set-up is adequate, EEG recording must be coupled to video.

If indicated, the screening of respiratory events requires the installation of polygraphy sensors, daytime nap recording or long-term recording.

The programming of a LTVER must be decided according to precise clinical indications.

In an emergency context, EEG can be performed in the laboratory or at the patient's bedside.

When performed at the bedside, the EEG must be recorded from a portable device.

When performed at the bedside, the EEG must be recorded by a qualified, experienced technician.

The recording technique for bedside EEG is identical to that performed at the laboratory, except for IPS, which is recommended but which cannot always be systematically performed depending on the availability of the photic stimulator.

The recording technique for bedside EEG can include a number limited to 10 electrodes.

In the context of an emergency, the EEG interpretation must be done within the day.

When suspecting abnormal movements, it is necessary to perform an EMG of relevant muscles coupled with video recording.

Indications

EEG in occasional epileptic seizures and status epilepticus in children

EEG is indicated in complex febrile seizures or febrile status epilepticus; it contributes to the diagnosis of encephalitis, brain abscess or early symptoms of epilepsy (yet cannot be a substitute for other diagnostic examinations such as lumbar puncture or brain imaging).

EEG is useful in the clinical context of seizures occurring in the first hours after a brain injury.

EEG is useful in convulsive or non-convulsive status epilepticus; it contributes to the diagnosis, can sometimes point towards etiological or prognostic orientation and helps in monitoring the efficacy of anti-epileptic drugs.

EEG is indicated in encephalopathy/coma (metabolic, post-anoxic, post-traumatic, toxic), as it can help assessing the severity of the condition and its prognosis. EEG can detect eventual complications (subclinical seizures) and may eventually orientate the etiological diagnosis.

EEG is indicated in children with acute confusion, acute behavioral disorders, and disorders of vigilance in addition to other diagnostic and etiological explorations.

Apparent life-threatening event in infants

EEG is not systematically indicated for an apparent life-threatening event in infants, except in newborns (inconclusive neurological exam), when the semiology of the event suggests epileptic seizures, or in the context of a history of neurological disorders, abnormalities in the neurological examination or delayed psychomotor development.

If apparent life-threatening events continue to occur daily and in the absence of an identified etiology (digestive, cardiac, vagal hypertonia, respiratory), an EEG-video recording with polygraphy tracings (ECG, respiration, EMG) is indicated to determine the potential epileptic origin of these events.

Autistic spectrum or intellectual disability in children

In screening for autistic spectrum disorders or intellectual disability in children, EEG (wakefulness and sleep recordings) is indicated in the context of a history of neurological disorders, abnormalities of the neurological exam or notion of cognitive regression, and validated or suspected epileptic seizures.

EEG in case of a first non-provoked seizure in children

EEG is indicated in case of a first non-provoked seizure in children: it contributes to evaluating the risk of seizure recurrence in addition to other clinical, radiological and anamnestic data.

Performing an EEG within 24 hours following a first paroxysmal clinical event, suspected of being epileptic in nature, can yield strong evidence when EEG abnormalities are specific and coherent with clinical data; however, the interpretation of abnormal slow waves can be difficult.

EEG indications in the case of epilepsy

EEG can help with the positive diagnosis of new-onset epilepsy by recording interictal abnormalities or seizures on video-EEG. The EEG should always be interpreted in association with complete clinical data [age, history, seizure type(s), clinical examination, learning abilities and neuropsychological development, brain imaging and medical treatments].

In certain cases, EEG can contribute to the diagnosis of the epileptic syndrome, from the first seizure, if all clinical elements match (e.g. benign epilepsy with rolandic spikes, benign occipital epilepsy of childhood).

Recording a typical absence seizure, which may be readily triggered by hyperventilation during an EEG performed at the laboratory, allows confirmation of the diagnosis of absence epilepsy.

Sleep EEG is essential for the diagnosis of epileptic encephalopathy with continuous spike-waves during slow-wave sleep (CSWS). A sleep recording should thus be systematically realized in children presenting regression of psychomotor acquisitions and rare or even absent nighttime seizures.

If specific reflex or trigger mechanisms are known or suspected, except for patients presenting generalized

seizures or with the risk of secondary generalized seizures, events/seizures should be triggered at the laboratory, for example, in childhood or adolescence absence epilepsy (hyperventilation), searching for reflex myoclonic seizures (myoclonic epilepsy in infancy), reflex seizures triggered by reading, noises, surprise, etc.

In case of doubtful origin of paroxysmal events in children and a minimal frequency of one event per 24 to 48 hours, an EEG-video recording is useful to refine the nature of these events.

In a patient with confirmed epilepsy, EEG contributes to treatment monitoring and should be performed according to the clinical context and to seizure control.

In neurodegenerative, chromosomal and metabolic diseases, EEG is indicated because of the increased incidence of epilepsy, epileptic encephalopathy, or non-convulsive status epilepticus (e.g. Rett syndrome, Angelman syndrome, Down syndrome, or lysosomal storage diseases).

EEG report

The report must meet the expectations of the clinician and answer the questions raised in the EEG request. The report includes two parts: description and conclusion.

The description of physiological figures is based on the frequency of the background rhythms (beta, alpha, theta, delta) as well as their location, amplitude, symmetrical or asymmetrical nature and their reactivity to stimulation procedures, e.g. opening of the eyes, auditory, tactile, nociceptive stimulations. This description concerns all behavioral states.

The EEG report should also include the description of pathological figures, such as spikes or spike-waves, or patterns that do not correspond to the patient's age or vigilance state.

Eventual EEG changes or appearance of other figures, during activation procedures, hyperventilation and IPS.

The electro-clinical description of all seizures if recorded with video-EEG, their number and circadian distribution.

Quantitative analysis of sleep stages when polysomnography has been performed.

Qualitative and quantitative analysis of potential cardiorespiratory changes.

The conclusion should be clear and precise using terms published in the glossary of recommendations published by the International League Against Epilepsy (ILAE) [25] (Non-consensual agreement, see chapter ''Proposal for writing EEG report forms'').

The requesting clinician expects a helpful conclusion in order to establish a diagnosis or sometimes a prognosis.

The limits of atypical events are quite wide in children, for a given age, with numerous normal variants; it is essential to know these variants before concluding as to a pathological recording, which could have immediate consequences in terms of diagnosis and treatment.

Full-length guidelines

Technique

This chapter focuses on EEG in infants, children and adolescents, excluding the neonatal period (from 1 month of age to 18 years) and its technical aspects according to age and indications (general pediatrics, emergency and epilepsy). This examination can be performed at any age; nevertheless, it requires a specific technique and needs to be interpreted by a physician experienced in pediatric EEG.

Test preparation and set-up

Pediatric EEG techniques are specific, whether for standard EEG, sleep EEG, or long-term video-EEG. Just as in adults, it is essential to review prior to the recording, information on clinical data and results from other examinations as well as medical treatments taken by the patients (anti-epileptic drugs or other drugs that could alter the recording). These elements allow better definition of the goal of the EEG, and recording techniques can thus be adapted to the clinical context.

Proper organization and set-up of the EEG recording guarantee its quality. Before the age of 5 years, recording sleep should be systematic since the awake EEG is often illegible because of movement artefacts; in addition, sleep EEG yields information on brain maturation, and furthermore certain abnormalities are only visible in nREM sleep [3,4,28,30]. It is also essential to continue recording for at least 15 minutes after the child wakes up, since some seizures, such as epileptic spasms in infants, usually occur upon arousal.

Sleep deprivation in older children enables daytime sleep EEG recording at the laboratory; sleep deprivation itself does not seem to increase epileptiform abnormalities during sleep [15]. Sleep can be easily obtained if the EEG appointment is given at the usual naptime and/or after bottle feeding or nursing (the child can be fed in the waiting room). When giving the appointment, the staff will advise parents to bring pacifiers, milk bottles/food and cuddly toy/blanket, and remind them to prevent the child from falling asleep when driving to the lab.

Pediatric EEG recording requires specific conditions and specially trained and skilled technicians.

The laboratory environment must be quiet, dimly lit, with a temperature between 19 and 20 °C, comfortable for children and their parents; objects and toys, a decoration adapted to children as well as soft music can be helpful to promote sleep. Each room dedicated to the EEG recording must be fitted with medical gas outlets (oxygen, air, aspiration) near the head of the bed or the recording chair. The unit should have an emergency trolley with ventilation masks adapted to the child's age (newborn, infant and child), two sizes of suction catheters, Guedel airways as well as midazolam for oromucosal or diazepam for intrarectal administration in case of prolonged seizure. The room should also have a sink to be able to clean the child's head (to wash off the water-soluble electrode paste).

The presence of one of the parents or legal guardian is strongly recommended during the EEG recording and essential in long-term EEG (day and night).

Electrode and polygraphic set-up techniques depend on the child's age, the clinical indication and the type of EEG recording.

Electrodes. There are several types of silver chloride electrodes (AgCl): cup electrodes, bridge electrodes and electrodes fitted directly into a headgear or soft cap (See

Appendix A). Invasive disposable needle electrodes are not used in this context. Electrodes are placed according to the International 10/20 System. Their number is adapted to the child's age and head circumference, and can be reduced to 12 (Fp1, Fp2, T3, T4, T5, T6, C3, C4, O1, O2, Cz and reference electrode). At the age of 5—6 months, the number of electrodes should be 17, with additional temporal (F7, F8), parietal (P3, P4) and vertex (Fz, Pz) electrodes or ideally 21, adding F3, F4, Pz and Oz especially for assessment of epilepsy [3,4]. The reference electrode should be placed in a presumed ''inactive'' zone, yet, it should still be positioned on the head, otherwise the recording will be subjected to artifacts (movement, EMG, ECG). We recommend reference electrode placement on the head but as far away as possible from an EEG source and hard for the child to reach (one mastoid for example). The ground electrode is usually extracephalic (shoulder) (see technique in chapter ''EEG in adults at the laboratory or at the bedside''/NCCN, this issue).

Other sensors. ECG (2 adhesive precordial electrodes) and respiratory rate (sensor placed on the thoraco-abdominal junction) recordings should be systematic. They are highly useful to interpret certain artifacts and essential in case of apnea or fainting spells, whether epilepsy-related or not. Measuring oxygen saturation can help detect oxygen desaturation during these paroxysmal events.

EMG of at least two corresponding muscles is indicated if abnormal movements are likely to appear during the test. Since the recording is bipolar a minimum of 4 EMG channels is needed. Two electrodes (adhesive gel electrodes) should be placed on the muscle concerned, 2 cm apart in the sense of their contraction (for example both deltoids in case of myoclonus or spasms). In case of atonic events, additional EMG over the neck and recording the patient in a sitting or upright position with arms extended is indicated.

Movements can also be recorded via an accelerometer (piezoelectric quartz that records the second derivative of the movement); this technique is useful for movement detection but not for detailed semiological analysis. Screening for respiratory events (e.g. sleep apnea) requires the simultaneous recording of respiratory movements on two different sites, chest and abdomen, and the measuring of the air flow, either with an oronasal airflow thermistor (measures temperature differences between the inhaled and exhaled air) or ideally by a pressure transducer placed in the nostrils. Only this simultaneous recording can differentiate central sleep apnea from obstructive sleep apnea.

For a detailed sleep study and to determine the different sleep stages, it is necessary to record eye movements (electrooculogram) using surface electrodes, with one placed 1 cm above the outer canthus of one eye and the other electrode placed 1 cm below the outer canthus of the other eye in addition to surface EMG of muscles beneath the chin.

Simultaneous video-EEG recording. Nowadays, simultaneous video recording is available on most EEG systems and does not require any specific set-up (apart from adjusting the camera field of view). Simultaneous video-EEG is recommended whenever possible; the video is helpful not only in precise semiological description but also helps in differentiating artifacts and determination of state of vigilance. Only the useful sequences of the video recording are to be stored.

Duration of the examination. The duration of the standard EEG recording without sleep should be between 20 to 30 minutes; when sleep is expected the recording should last from 45 minutes to 1 hour.

Technical specificities according to age and clinical circumstances

EEG in the laboratory in children under the age of 5 years. Systematic sleep EEG recording is recommended at this age, with the least disturbing set-up possible to promote falling asleep. After skin abrasion, we recommend using cup electrodes fixed with conductive paste and a gauze pad, the entire set-up being held by a lightweight surgical mesh head cap. Soft caps with fitted electrodes and head caps with straps are also commonly used in children of this age. Sizes of the soft caps and straps are adapted to the child's head circumference. Naptime EEG always starts with a wakefulness recording, including hyperventilation when feasible, and IPS, followed by a 20 to 40-minute sleep recording, to obtain light and deep slow-wave sleep, finishing with the patient's arousal from sleep, whether or not REM sleep was recorded.

Standard EEG in children above the age of 5 years. Good quality wakefulness EEG is possible in a cooperative child from the age of 5 or 6 years. We can use classic caps with plastic straps and chin holders or soft caps with fitted electrodes, or cup electrodes in younger children (see Appendix A). The technical set-up is comparable to EEG in adults using 17 to 21 electrodes of the International 10/20 system and according to the clinical context [3] (see technique in chapter ''EEG in adults at the laboratory or at the bedside''/NCCN, this issue).

Daytime sleep (nap) EEG in children older than 5 years. This requires the same set-up as described above; sleep deprivation is recommended (going to bed late the night before and getting up early; making sure that the child does not fall asleep on the way to the laboratory). In case of failure to fall asleep spontaneously, and if the indication for sleep recording is maintained, administering melatonin (in the first 15 minutes of the set-up) can be proposed in addition to the previously described preparation [16].

Emergency EEG. Emergency EEG is performed within 24 hours after hospitalization or consultation for suspicion of epilepsy, vigilance and behavioral disorders or confusion syndrome [23]. This type of EEG can be performed either at the laboratory, or at the patient's bedside in the pediatrics unit or in the ICU. For bedside recording, it is essential to have a portable device with a sturdy head box; the number of channels might be lower compared the head box on the fixed device in the EEG laboratory. Bedside and ICU EEG recording requires also a dedicated well-experienced EEG technician, trained in EEG techniques and in handling recording of patients in a coma or in the ICU (e.g. artifacts related to the presence of other electrical devices; dealing with weak and unstable patients).

Furthermore, the recording techniques and conditions of the bedside and ICU EEG are similar to those in laboratory EEG; the difference concerns the number of electrodes, which can be limited to 10 (Fp1, Fp2, T3, T4, C3, C4, O1, O2, Cz and reference electrode), hyperventilation and IPS procedures (according to the patient's cooperation and

contraindications), and sensory and nociceptive stimuli (in case of vigilance disorders or coma) in order to evaluate EEG reactivity. The type of stimulation as well as an eventual clinical response must be noted when performed by the technician. Any event that could potentially alter the EEG or trigger artifacts during the recording must also be noted. The EEG should be interpreted as quickly as possible in emergency situations (see chapter ''Continuous EEG monitoring in children in the intensive care unit (ICU)''/NCCN, this issue).

Test procedure

Amplitudes, montages and filters can be changed a posteriori. It is recommended to use bipolar and/or mean reference montage, especially if artifact correction is necessary. Furthermore montage changes can be recommended during data acquisition; some focal abnormalities (spikes or spike-and-wave) are more easily seen, or only detectable, on a transversal montage versus a longitudinal one or vice versa. Electrode impedance should not exceed 5 Kohms in order to ensure good quality recording. In case of asymmetry, distances between electrodes should be verified and noted. Any event, movement, opening/closing of the eyes as well as vigilance state and it changes should be indicated on the recording by the technician. Eventual artifacts should be corrected and electrodes and impedance must be verified.

As in adult EEG, pediatric EEG should include eyes closed and eyes open periods when the child cooperates. In infants, from the age of 3 months onwards, background occipital rhythm can be obtained with passive closure of the eyes, obtained by the technician gently placing a shield (cotton pad for example) on the infant's eyes [28,30].

As soon as possible, sometimes from the age of 3 years, mostly from the age of 5—6 years, two hyperventilation procedures should be performed during the EEG, and the recording should last for at least one more minute after the end of the hyperventilation procedure. In younger children, hyperventilation (HV) can be obtained by asking them to blow on a pinwheel; crying and sobbing also promote hyperventilation [38].

In children, hyperventilation bears the same contraindications as in adults (recent ischemic stroke, intracranial hemorrhage, sickle cell disease) as well as Moya-Moya disease [3,4,21].

Intermittent photic stimulation procedure with increasing frequencies from 1 to 60 Hz should be performed as soon possible depending on age and clinical conditions. It should be carried out at least 3 minutes before or after the hyperventilation procedure. IPS yields little information before the age of 12 months but promotes sleepiness in infants who are generally attracted by the light and stare at the photic stimulator.

The different ocular conditions (eyes open, during eye closure and eyes kept closed) should be tested according to the technique described in adults [20]; cooperation is generally present by the age of 4 years. When there is very little time or in a non-cooperative child, we recommend stimulation with 7-second trains: eyes open, followed quickly by eye closure and finally keeping the eyes closed until the end of the stimulation train. When a photoparoxysmal response occurs at a given frequency (starting with low frequencies), stimulation should be stopped, then started again at 60 Hz to find the frequency < 60 Hz that is responsible for the photoparoxysmal response [20]. The patient should be observed, videoed and we recommend using EMG electrodes positioned on the deltoids to detect eventual myoclonus of the limbs and/or eyelids or when photosensitive epileptic seizures are suspected. Low-frequency IPS (0.5—2 Hz), for a period of 1 to 2 minutes can be used to screen for progressive myoclonic epilepsy. When visually induced seizures are suspected to be related to video games, a photoparoxysmal response can be triggered by using video games at the laboratory (e.g. Pokemon™) [20]. During a seizure, whenever possible, the technician and/or physician should try and interact with the patient to test alertness, reactivity, language and motor skills during and after the seizure (see technique in chapter ''EEG in adults at the laboratory or at the bedside''/NCCN, this issue).

EEG analysis

EEG analysis and reporting requires a complete knowledge of the child's medical record, clinical data, results from other additional examinations and medical treatments.

To facilitate EEG interpretation, the physician can change the amplifier filters on each channel or on all of them, and adjust the EEG display speed. Display speed can be higher or lower than 15 mm/s. Other recorded parameters (ECG, respiratory channels, surface EMG) are also analyzed for the report.

For each electrode, the density spectral array (DSA) with a frequency range from 0 to 30 Hz can condense 8 hours of EEG recording and display simultaneously 8 channels on the screen. In long-term recordings, it is a useful tool for physicians to quickly identify changes in the vigilance state, and occurrence of paroxysmal events. This condensed analysis does not however replace detailed EEG analysis, especially for long-term EEG recording [28].

The EEG report must meet the expectations of the requesting physician and answer the questions raised in the EEG request. The report includes two major parts: description and conclusion [28].

EEG description

Description of physiological figures

This is written according to the frequency of the background activity (beta, alpha, theta, and delta) and their location, amplitude and eventual symmetric nature as well as reactivity (opening of the eyes, auditory, tactile and nociceptive stimuli). This description concerns all states of vigilance.

Description of pathological figures

These can be characteristic figures, such as spikes or spike-and-wave, or figures that are inadequate based on age or level of alertness.

Eventual changes during stimulation procedures: hyperventilation and IPS

Activation of preexisting figures or onset of new figures must be noted.

Description of the EEG aspect and eventual recorded seizures
The description should include their number, circadian distribution, as well as a clinical description in case of video recording.

Quantitative analysis of sleeping stages in polysomnography.
Qualitative and quantitative analysis of eventual cardiorespiratory changes.
Conclusion
In the EEG report, the conclusion must be clear and precise, using terms from the glossary of guidelines published by International League Against Epilepsy [25]. The requesting physician expects diagnostic and sometimes prognostic help. Normal variants and unusual aspects of EEG are quite wide in children, as well as ''atypical events''; it is essential to know these variants before concluding as to a pathological result, which could have immediate consequences in terms of diagnosis and treatment. [28].

Indications in pediatric EEG

EEG is essential

In cases of complex febrile seizures and in febrile status epilepticus, EEG contributes to the diagnosis of encephalitis, brain abscess (in the presence of focal abnormalities) and new-onset epilepsy [1]. EEG is not indicated in simple febrile seizures [2].

In the case of status epilepticus, convulsive or not, EEG contributes to diagnosis, can help orientate towards an etiology, and refine treatment surveillance [1].

In encephalopathy and coma, EEG can help assess severity and prognosis of encephalopathy and eventually define its nature (e.g. toxic, metabolic, hepatic or post-anoxic) [22]. In severe traumatic brain injury (TBI), EEG is indicated in the first 24—48 hours to assess TBI prognosis and screen for subclinical seizures [1] (see chapter ''Continuous EEG monitoring in children in the intensive care unit (ICU)''/NCCN, this issue).

In cases of acute confusion, behavioral disorders or alertness disorders, EEG can help orientate the etiology, allows classification of four severity stages and adds to prognosis [23].

In first unprovoked seizure (of unknown origin), EEG can help assess the risk or recurrence in addition to clinical data. After a first unprovoked seizure, only 40% of children will present a second seizure during the following year [33]. After a second seizure, the rate of recurrence increases to 70% [34]. The risk is higher if there is a family history of epilepsy, a history of neurological pathology, or abnormalities in psychomotor development, neurological examination and brain imaging [33,34]. In this case, the diagnosis of new-onset epilepsy can be made and an anti-epileptic treatment started after the first seizure [17]. The diagnosis of epilepsy should not be made after a first clinical event of doubtful nature and the presence of some spikes on the EEG recording. Isolated spikes or generalized spike-and-wave bursts can be observed in 3 to 4% of normal school-age children who will never become epileptic [13]. EEG performed early, during the first 24 hours following a paroxysmal manifestation, can help validate the epileptic origin. Interpretation of slow waves, however, can be quite difficult since these abnormalities are seen not only in the post-ictal phase but also after acute migraine [1].

In the diagnosis of epilepsy and the follow-up of epileptic patients, EEG is essential for the following.

Positive diagnosis and syndromic diagnosis
In some cases, EEG can help validate the diagnosis of new-onset epilepsy by recording interictal abnormalities and/or typical ictal events on video-EEG [5,24,29]. This is the case for example, in benign epilepsy with centrotemporal spikes with rolandic seizures occurring during sleep in an otherwise healthy child. EEG recording with interictal centrotemporal biphasic spikes activated during sleep is highly typical of this diagnosis. Similarly, the diagnosis of childhood absence epilepsy is validated by recording characteristic absence seizures triggered by hyperventilation.

When suspecting visually induced seizures, screening for photosensitivity is relevant both for the positive diagnosis of epilepsy and the syndromic diagnosis, especially in generalized epilepsies [20,37].

Generalized spike-wave bursts or photosensitivity point towards idiopathic generalized epilepsy, whereas localized abnormalities are characteristic of idiopathic or symptomatic focal epilepsy. The topography of these focal abnormalities on the EEG can help identify the underlying brain lesions on the MRI.

Sleep EEG is essential for the diagnosis of epileptic encephalopathy with continuous spike-and-wave during sleep (CSWS), which should be systematically looked for in children with regression or stagnation of psychomotor and language acquisitions and rare or even absent night time seizures [31].

Whenever seizures can be recorded (excluding those that are generalized or secondary generalized), triggering seizures at the laboratory is recommended: for example, in childhood or adolescent absence epilepsy (hyperventilation); provoked reflex myoclonus (myoclonic epilepsy in infancy); reflex epilepsy triggered by reading, hot water, noise or surprise; negative myoclonus in CSWS syndrome; epileptic spasms on arousal.

Long-term video-EEG should be suggested in new-onset epilepsy if standard video-EEG recording with sleep did not lead to a syndromic diagnosis and if seizure frequency is sufficient in order to record at least one seizure during 24—48 hours (which is the case for most epileptic syndromes in this age range) [35] (see chapter ''Long-term EEG in Children''/NCCN this issue).

Differential diagnosis
In newborns, infants, children and adolescents, the differential diagnosis of paroxysmal events between an epileptic and non-epileptic origin is often a challenge. Video-EEG can be an essential tool to refine the nature of these events: e.g. paroxysmal events in alternating hemiplegia of childhood, hyperekplexia with tonic spasms, tonic upgaze or paroxysmal kinesogenic dyskinesia. Psychogenic seizures tend to occur in older children or adolescents and are often difficult to recognize, especially since they can also

happen in epileptic patients. In this last case, EEG recording of paroxysmal events is part of the diagnostic work-up and can improve the epileptic and psychiatric management.

Etiological diagnosis
In some cases, EEG can point to an etiology based on typical figures and spatio-temporal organization of characteristic abnormalities. This is the case in symptomatic epilepsy and some cortical malformations (e.g. lissencephaly, hemimegalencephaly, cortical focal dysplasia), chromosomal abnormalities (Angelman syndrome, Ring chromosome 20 syndrome), symptomatic epilepsy of certain neurodegenerative diseases (neuronal ceroid lipofuscinosis, infantile neuroaxonal dystrophy) [29].

Epilepsy follow-up
In a patient with known epilepsy, EEG contributes to treatment follow-up and should be requested according to the clinical situation and quality of seizure management.

When epilepsy is properly managed, with absent or rare seizures in children with good psychomotor development, EEG should be performed every 6 to 12 months, or at longer intervals according to clinical data and epileptic syndrome. The timing of an EEG before and after eventual AED withdrawal depends on the epileptic syndrome (e.g. no systematic EEG follow-up in benign epilepsy with centrotemporal spikes in the absence of new clinical signs; EEG performed 3 to 6 months after AED withdrawal in childhood absence epilepsy) [8].

In epileptic encephalopathy (West syndrome, CSWSS, Lennox-Gastaut syndrome), in addition to close clinical monitoring, management must include EEG monitoring to ensure treatment effectiveness as well as the disappearance of seizures and interictal EEG abnormalities. EEG and preferably video-EEG should be systematically carried out in the event of seizure recurrence or unexplained changes of seizure semiology, and when the initial diagnosis is questioned. EEG should also be performed for unexplained disorders of consciousness in epileptic patients to screen for non-convulsive status epilepticus.

EEG can be relevant...

EEG is relevant in epileptic seizures occurring in the first hours after traumatic brain injury (TBI); however, there is no indication for EEG in the absence of epileptic seizures post-TBI or TBI without loss of consciousness [1,26]. See chapter ''Continuous EEG monitoring in children in the intensive care unit (ICU)''/NCCN this issue.

In apparent life-threatening event (ALTE) in infant, EEG should not be systematic, and its indication must be adapted to each individual case. As a matter of fact, without any clinical evidence of epileptic origin, the diagnostic contribution of EEG is quite weak since the most frequent causes of ALTE are digestive (50%), neurological, including vagal hypertonia (30%) and respiratory (20%) [11,12,36]. Epileptic seizures seem to be involved in only 5 to 10% of cases [11,36]. EEG is indicated if the semiology suggests an epileptic origin (repeated seizure, stereotyped event, no other identified cause) and when the patient has a history of neurological disorders. For some authors, EEG should be systematically performed in children under the age of 3 months to screen for potential epilepsy, because of the atypical and often subtle ictal manifestations at that age [14]. If episodes occur on a daily basis, long-term video-EEG is indicated after having excluded the most frequent causes. The Consensus document of the European Society for the Study and Prevention of Infant Death recommends that explorations should be guided by the clinical condition and suspected etiology and the choice should be left to the physician based on data collected during the clinical examination and patient interview [19].

In patients with autistic spectrum disorders, there is an increased incidence of epilepsy and EEG abnormalities even in the absence of epilepsy. However, no study has validated a link between EEG abnormalities, epilepsy and autistic-type regression except in CSWSS syndrome (especially Landau-Kleffner syndrome) [18,27,39]. The indication for sleep EEG seems obvious in this context, that is, cases of autistic regression associated with regression or stagnation in language with or without epileptic seizures. EEG is also indicated in autistic spectrum disorders associated with validated or suspected epileptic seizures. Some paroxysmal events, especially behavioral ones, are difficult to differentiate from epileptic seizures. The incidence rate of epilepsy in patients with autistic spectrum disorder ranges from 7 to 42% according to the various studies, and increases in patients with psychomotor developmental delay and abnormalities in the neurological examination; EEG is useful in this situation [9].

The Practice Committee of the Child Neurology Society published guidelines stating that EEG is not systematically indicated in intellectual disability, except in the case of epileptic seizures [32]. For other authors, EEG should be systematic as part of the etiological assessment [7].

In children with specific language disorders, the incidence of EEG abnormalities is higher vs. the normal pediatric population (20%), however, aside from CSWSS syndrome, these abnormalities do not seem to yield any prognostic value and anti-epileptic treatment is not indicated [10].

In cerebral palsy, EEG is only indicated in the case of seizure history or an unexplained psychomotor regression [6].

In neurodegenerative, genetic and metabolic diseases, EEG can be useful (though no official guidelines have been published) because of the increased incidence of epilepsy, epileptic encephalopathy and status epilepticus (convulsive or non-convulsive) in syndromes that can contribute to clinical aggravation and psychomotor regression (e.g. Rett Syndrome, Angelman Syndrome or Down Syndrome). A reference EEG is useful for patient follow-up, performed when the child is considered as healthy as possible and it can allow the physician to compare further EEGs to the reference one, when faced with eventual clinical changes or when the patient has reached adulthood.

Disclosure of interest

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

Appendix A. Pediatric EEG accessories

EEG Headcaps

There are several types of head caps:

- classic head caps with plastic straps and chin holders. Two types of head caps should be differentiated according to the electrodes. Soft cap for bridge electrodes, adjustable, made of elastic straps lining into plastic pins and connected to plastic pads positioned under the ears. Easy to set-up and adjust, this type of head gear is convenient for adults and children alike; however, its disadvantage is the need to tighten up the straps with the risk of pulling hair, pinching the skin or being uncomfortable for falling asleep;
- PTS elastomer soft cap. PTS is a special elastomer that perfectly adjusts to the patient's head. They are available in three sizes and three different diameters: each color corresponds to a specific diameter;
- ''mesh-like'' soft cap made of latex-free silicone fastened to an elastic band with support hooks for the cup electrodes (Netcap®), the elastic band is lined with silicone to guarantee proper fixation during the EEG test. Advantage: the user can personalize the cap with the number of derivations needed;
- disposable cap with fitted electrodes (Dispocap®) respecting the 10—20 montage and made of two parts that screw together so the technician can change the position of the electrodes even during the recording. This device is provided with 20 tin electrodes already fitted into the soft cap and one additional electrode to be used as a reference electrode;
- head cap where the soft silicone electrode holders are already inserted into the cap along with fitted leads to avoid oxidation risks (Softcap®); to be used with tin or Ag/AgCl electrodes;
- EEG-Comby® head cap with the 10/20 system in 6 different sizes;
- Electrocap® made of elastic fabric with tin electrodes.

The mesh cap and leads can be sterilized via autoclave and on demand. Silicone caps must be cleaned in a special solution after each use.

All head caps are available in different sizes with specific diameters for newborns, infants and children and the electrodes must always abide by the 10/20 montage.

In newborns and infants, because movements are difficult to control, it is recommended to use cup electrodes.

Electrodes

Among electrodes used on the classic EEG cap we can differentiate several different ones:

- common bridge electrode, the most common one, is made of a fine silver rod (Ag—AgCl) enlarged at the extremity in contact with the scalp. This silver rod is fixed in a plastic support, ensuring the stability of the electrode it must be wrapped in cotton and gauze to avoid injuring the skin;
- AgCl cup electrodes with their connecting leads are hollow and punctured in the middle to be filled with conductive gel and maintained with the Tensive® paste. They are positioned on the scalp according to the international 10/20 system, and maintained with a light mesh;
- round or rectangular adhesive electrodes, already coated with conductive paste, and their leads are also positioned according to the international 10/20 system and maintained with a soft mesh cap.

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