GUIDELINE

American Clinical Neurophysiology Society: EEG Guidelines Introduction

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Summary: This revision to the EEG Guidelines is an update incorporating current EEG technology and practice. "Standards of practice in clinical electroencephalography" (previously Guideline 4) has been removed. It is currently undergoing revision through collaboration among multiple medical societies and will become part of "Qualifications and Responsibilities of Personnel Performing and Interpreting Clinical Neurophysiology Procedures." The remaining guidelines are reordered and renumbered.

Key Words: EEG, Guideline, EEG equipment, EEG electrode, EEG montage, EEG brain death, EEG report, Adult, Pediatric, Neonatal.

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Guideline 1: Minimum Technical Requirements for Performing Clinical EEG

Digital equipment has many advantages over analog equipment and is now used for EEG in most facilities. Some recommendations in this guideline have changed to reflect the greater functionality of digital equipment, including the ability to record good quality signal with nontraditional electrodes and slightly higher impedances. The list of basic patient information has been expanded to include more factors that can influence the EEG. The sections on calibration, sensitivity, filters, and recording montages have been updated to maintain relevance for digital systems. Newly added sections include those discussing the utility of longer recordings, sleep deprivation, and simultaneous video recording. Other new sections include material on photic stimulation procedure, interpreting physician notification of critical EEG results, and data storage.

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Guideline 2: Guidelines for Standard Electrode Position Nomenclature

This was previously published as Guideline 5. Although the 10-10 system of electrode position nomenclature has been accepted internationally for almost two decades, it has not been used universally. The reasons for this and clinical scenarios when the 10-10 system provides additional localizing information are discussed in this revision. In addition, section IV elaborates on situations in which AF1/2, AF5/6, PO1/2, and PO5/6 electrode positions may be used for EEG recording.

Guideline 3: A Proposal for Standard Montages to be Used in Clinical EEG

This was previously published as Guideline 6. A discussion of methodology for the appropriate selection of reference electrodes is added. In addition, montages are added to assist with localization of abnormal activity in mesial frontal and anterior temporal regions.

Guideline 4: Recording Clinical EEG on Digital Media

This was previously published as Guideline 8. Recording parameters have been updated to reflect the higher level of resolution provided by current technology. Also, types of storage devices have changed since the earlier version of this guideline, and recommendations are made for digital storage to ensure durability and Health Insurance Portability and Accountability Act compliant accessibility as computer technology continues to evolve. Finally, details on the minimum computer screen display resolution have been updated.

Guideline 5: Minimum Technical Standards for Pediatric EEG

This was previously published as Guideline 2, and, similar to the previous guideline, delineates aspects of Guideline 1 that

should be modified for neonates and young children. Recording conditions for photic stimulation and hyperventilation were revised to enhance provocation of epileptiform discharges. Changes were also made to recognize the difficulties involved in performing an EEG under sedation in young children. Recommended neonatal EEG montages are displayed for the reduced set of electrodes only since the montages in Guideline 3 should be used for a 21 electrode 10-20 system array. Neonatal documentation has also been updated to use current American Academy of Pediatrics term "postmenstrual age" rather than "conceptual age." Finally, because therapeutic hypothermia alters the prognostic value of neonatal EEG, it is necessary to document the patient's temperature at the time of recording.

Guideline 6: Minimum Technical Standards for EEG Recording in Suspected Cerebral Death

This was previously published as Guideline 3. This update takes into account more recent publications on brain death criteria and artifacts. With modern technology, grounding from other electrical equipment is no longer a concern, and Guideline 1 recommendations to use a ground electrode should be followed. The 10-10 system electrode positions can be used when equivalent to the recommended 10-20 system locations. Sensitivity settings now reflect digital recording technology. Simultaneous video recording has become available widely and is recommended as a helpful adjunct in cerebral death recordings. A new section specifies factors that can lead to an inaccurate determination of cerebral death.

Guideline 7: Guidelines for Writing EEG Reports

This is a revision of the previous Guideline 7 "Writing an EEG Report" and is intended to provide an update for routine EEG reporting. The goal is not only to convey clinically relevant information but also to improve interrater reliability by standardizing the format of EEG reports. With this goal in mind, there is expanded documentation of the patient history to include more relevant clinical information that can affect the EEG recording and interpretation. Recommendations for the technical conditions of the recording are also enhanced to include post hoc review parameters and type of EEG recording. Sleep feature documentation is also expanded upon. More descriptive terms are included for background features and interictal discharges that are concordant with recent efforts to standardize terminology. In the clinical correlation section, examples of common clinical scenarios are provided to encourage uniform reporting. Including digital samples of abnormal waveforms is now possible and beneficial in augmenting reports when controversial waveforms or important features are encountered.

GUIDELINE

American Clinical Neurophysiology Society Guideline 1: Minimum Technical Requirements for Performing Clinical Electroencephalography

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Although no single best method exists for recording EEGs under all circumstances, the following standards are considered the minimum for the usual clinical recording of EEGs in all age groups except the very young (see also Guideline 5: *Minimum Technical Standards for Pediatric Electroencephalography*. Sections where modifications are recommended are delineated by ^for neonates and *for older children).

This document discusses minimum requirements; following these requirements alone does not ensure a satisfactory test. Each laboratory should strive for excellence in all aspects of study performance. Recommendations to improve standardization of procedures and to facilitate interchange of recordings and assessment among laboratories in North America have also been included. More detail is provided in recommendations from the International Federation of Clinical Neurophysiology (IFCN).[1]

1. EQUIPMENT

1.1 ^To display the distribution of EEG activity, it is necessary to record simultaneously from as many regions of the scalp as possible. When too few channels are used, the chances of interpretive errors increase; conversely, when more channels are used, the likelihood of such errors decreases. This is particularly true for transient activity.

Sixteen channels of simultaneous recording are considered the minimum number required to show the areas producing most normal and abnormal EEG patterns.

Additional channels are often needed for monitoring other physiologic activities and for highlighting activity recorded in specific regions.

1.2 Alternating current (AC) wiring should meet the Underwriters Laboratories standards required for hospital service, as per state and local electrical codes.

1.3 In the usual clinical setting, electrical shielding of the patient and equipment is not necessary, and such shielding need not be installed unless proven necessary.

1.4 Ancillary equipment should include a device for delivering rhythmic, high-intensity flash stimuli to the patient.

1.5 Digital EEG equipment should be used for recording. Digital equipment provides multiple advantages over paper-based EEG recording amplifiers, including greater sensitivity, greater reliability, the possibility of postrecording modification of EEG waveform rendering (gain, filters, montage), and more efficient EEG storage. Digital equipment should conform to the recommendations in Guideline 4: *Recording Clinical EEG on Digital Media*.

2. ELECTRODES

2.1 ^*Recording electrodes should be free of inherent noise and drift. They should not significantly attenuate signals between 0.5 and 70 Hz. Experimental evidence suggests that silver—silver chloride or gold disk electrodes held on by collodion are the best, but other electrode materials and electrode pastes have been used effectively, especially with contemporary amplifiers having high-input impedances.

Electrodes must be disinfected with appropriate procedures and transmission-based precautions taken after recording from patients with contagious diseases (e.g., viral hepatitis, Creutzfeldt–Jakob disease, acquired immunodeficiency syndrome).[2] Disposable electrodes may be considered as another option for reducing the risk of iatrogenic infections.

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2.2 Needle electrodes are not recommended for routine clinical use. Beyond considerations of patient discomfort and risk of injuries to personnel, these electrodes have higher impedances than appropriately applied cup electrodes, resulting in potentially higher levels of noise. Subdermal needle electrodes (SNE) or wire electrodes (SWE) may be used for prolonged recording of EEG in stuporous or comatose patients in situations where application of cup electrodes is not feasible because of personnel or time constraints. Although impedances are usually higher, they are usually well-matched and stable over long recording periods. Manufacturer's recommendations for insertion, removal, and disposal of each product are available and should be followed.

2.3 ^All 21 electrodes and placements recommended by the IFCN[3] should be used. The 10 to 20 System is the only one officially recommended by the IFCN. It is the most commonly used system and should be used universally. The use of the term "modified 10 to 20 System" is undesirable and misleading when it means that head measurements have not been made and placements have been estimated. In this case, the term "estimated 10 to 20 placement" is more appropriate. The term "10 to 10 System" should be used for the extended combinatorial system described in Guideline 2: *Guidelines for Standard Electrode Position Nomenclature* (For neonates, refer to Guideline 5). With some differences in naming, electrodes in the 10 to 20 System are included in the 10 to 10 System (T3 and T4 in 10–20 system are renamed T7 and T8 in 10–10 system; T5 and T6 in 10–20 system are renamed P7 and P8 in 10–10 system).

An adequate number of electrodes are essential to ensure that EEG activity having a small area of representation on the scalp is recorded and to analyze accurately the distribution of more diffuse activity. A smaller number of electrodes may be appropriate for special circumstances but is not considered comprehensive. Occasionally, additional electrodes, placed between or below those representing the standard placements, are needed to record localized activity better. The 10 to 10 System provides a standardized option for selecting additional electrodes.

In every case, an isolated ground electrode should be placed and connected to the jackbox as specified by the manufacturer. The isolated ground does not allow dangerous currents to pass and is not a safety hazard as were earth grounds used in early analog EEG devices. No electrode should ever be connected to the chassis of the equipment or to the earth ground. In addition, most digital equipment requires one or more system reference electrodes. These should be placed as suggested by the manufacturer.

2.4^*Interelectrode impedances should be checked as a routine prerecording procedure. With modern digital EEG recording equipment, impedances up to 10 k Ohms are acceptable,[4] but optimal recording still requires impedances that are balanced.[5] Unbalanced impedances compromise the ability of an EEG amplifier to reject potentials that are the same at a pair of electrodes while amplifying those that are different (common mode rejection). Impedances should also not be below 100 Ohms because this usually indicates a shunt or short circuit, possibly related to a salt bridge on the scalp.

Electrode impedances should be rechecked during the recording when any pattern that might be artifactual appears. Still, artifacts may appear even in electrodes with acceptable impedances. Thus, a normal impedance in an electrode demonstrating noise may still indicate the need to change or modify that electrode.

3. RECORDINGS

Montages should be designed in conformity with Guideline 3: *A Proposal for Standard Montages to Be Used in Clinical Electroencephalography*. It is desirable that at least some montages in all laboratories be uniform to facilitate communication and comparison. Digital systems allow reformatting of montages to provide optimal display of activity at the time of interpretation. To permit this flexibility, initial recording must be made from a referential montage, but the system reference itself cannot easily be reformatted. For this reason, the digital recording reference should be an additional electrode (or combination of electrodes) and not one of those in the 10:10 or 10:20 system. An additional electrode between Cz and Pz is commonly used. The use of linked ears as a digital recording reference is specifically discouraged.

3.1 ^*The information associated with the record should include, as a minimum, the name and age of the patient, the date of the recording, an identification number, and the name or initials of the technologist.

Identifications should be made at the time of recording. Failure to do so may result in errors that have adverse medical and legal consequences. A Basic Data Sheet, associated with every record, should include patient name and age, the time and date of the recording, name/initials of the technologist, indication for the EEG (including description of symptoms or events, and their frequency), the time and date of the last seizure/episode (if any), the behavioral state of the patient, a list of all medications the patient has been taking (including premedication given to induce sleep during EEG), presence and location of any skull defects, and any relevant additional medical history. Any additions or modifications to standard electrode placements must be noted. Additional items that are helpful include handedness, time of last meal, and whether patient was sleep-deprived for the study. The results of previous neurophysiological testing, especially EEGs, should also be included when available.

3.2 Appropriate calibrations should be made at the beginning of every EEG recording. This includes at least 10 seconds (or the duration needed to reach a stable recording) of a square wave calibration. For analog systems, a recording with all channels connected to the same pair of electrodes should follow at the beginning (biologic calibration). At the outset, all channels should be adjusted, if necessary, so that they respond equally and correctly to the calibration signal. When doubt as to correct functioning of any amplifier exists, a repeat calibration run should be made. Biologic calibration is not necessary for digital systems.

In addition to the standard square-wave calibration, the biologic calibration may occasionally help in detecting errors in the montage selection process or in the pen-writing mechanism for analog recordings. For this purpose, an anteroposterior (frontooccipital) derivation should be used because it can include fast and alpha range patterns as well as eye movement activity in the delta range.

The calibration is an integral part of every EEG recording. It gives a scaling factor for the interpreter and tests the EEG machine for sensitivity, high-frequency and low-frequency

response, noise level, and pen alignment and damping (for analog systems). Calibration voltages must be appropriate for the sensitivities used during the recording. After calibration, visual review of a 30-second run on the system reference montage without the notch filter is also recommended.

3.3 ^*The sensitivity of the EEG equipment for routine recording should be set in the range of 5 to 10 μV/mm of trace deflection. Sensitivity is defined as the ratio of input voltage to trace deflection. It is expressed in microvolts per millimeter. A commonly used initial sensitivity is 7 μV/mm, which, for a calibration signal of 50 μV, results in a deflection of 7.1 mm. If the sensitivity is decreased (for example, from 7 to 10 μV/mm), the amplitude of the waveform visualized on the EEG also decreases. Conversely, if the sensitivity is increased (e.g., from 7 to 5 μV/mm), the amplitude of a given waveform increases on the EEG.

When the sensitivity is less than 10 μV/mm (e.g., 20 μV/mm), significant low-amplitude activity may become undetectable. If the sensitivity is greater than 5 μV/mm (e.g., 3 μV/mm), normal EEG activity may obscure the tracing and limit identification of individual waveforms and frequencies.

With digital systems, this straightforward physical relationship of sensitivity (millimeter of pen deflection for μV of input voltage) is lost. Systems can be calibrated for a specific screen, so that sensitivity retains its physical meaning. When the same data are redisplayed on a different computer monitor, however, this relationship may be lost. For this reason, clear scale markers must be shown as part of the display.

During calibration for routine recordings, the recorded signals should not be distorted but should be large enough to permit measurement to better than ±5% between any of the signals on the different channels.

No matter which sensitivity (within the above limits) is chosen before the recording, appropriate adjustments should be made whenever the EEG activity encountered is of too high or low amplitude to be recorded properly.

3.4 ^For digital recordings, filtering of the signal occurs at two levels. Analog filters are applied to the incoming signal in the actual amplifier before digitization. These are usually dependent on the specific amplifier being used and not modifiable by the user, but they do define the ultimate range of frequencies being recorded and are important to keep in mind when digitally filtering the signal after collection.

The second level of filtering consists of digital filters that are applied before display of the digitized data. These filters are analogous to the filters traditionally used in analog EEG recording, but unlike in analog recordings, the use of these filters in digital recordings does not permanently alter the recorded data; it only processes the data for display. Proper use of digital filters during data collection is still important. Improper use of digital filters may prevent the technologist from recognizing relevant EEG abnormalities, artifacts, or changes in electrode impedances that will negatively impact the quality of the recording. For standard recordings, the low-frequency filter should be no higher than 1 Hz (−3 dB), corresponding to a time constant of at least 0.16 second. The high-frequency filter should be no lower than 70 Hz (−3 dB). Note, however, that to display frequencies as high as 70 Hz, a computer monitor would need a horizontal resolution of at least 1,400 pixels in the data display area. Interpreters should be aware that some loss of high-frequency resolution will otherwise occur, along with the possibility of lower-frequency distortion because of spatial aliasing.

A low-frequency filter setting higher than 1 Hz should not be used routinely to attenuate slow-wave artifacts in the record. Vital information may be lost when pathologic activity in the delta range is present. Similarly, a setting lower than 70 Hz for the high-frequency filters can distort or attenuate spikes and other pathologic sharp features into unrecognizable forms and can cause muscle artifact to resemble spikes. Production of a record with lost or inaccurate information is poor medical practice.

It must be emphasized, however, that judicious use of the low-frequency or high-frequency filters—with appropriate annotation on the record—can emphasize or clarify certain types of patterns in the record. These filter controls, therefore, should be used selectively and carefully.

3.5 The 60-Hz (notch) filter can distort or attenuate spikes; it therefore should be used only when other measures to reduce 60 Hz interference fail.

3.6 A display of 10 to 20 seconds/page (depending on the size of the display) should be used for routine recordings (corresponding roughly to a paper speed of 30 mm/second typically used on paper EEG systems). A display of 15 to 30 seconds/page is sometimes used for EEG recordings in newborns or in other special situations.

3.7 ^The baseline record should contain at least 20 minutes of technically satisfactory recording. Longer recordings are often more informative. Although the ability to reformat a digital EEG during display allows the entire recording to be viewed in any montage after the recording, displaying the data during acquisition in only a single montage is not an acceptable practice. The EEG technologist acquiring the recording should view the EEG in at least 3 different montages (including at least one bipolar and one referential montage) during the recording to improve the ability to identify poor connections in electrodes that may not be apparent in certain montages and also to allow appreciation of subtle abnormalities that require special technical maneuvers (such as placement of additional electrodes).

The EEG is a short sample of brain activity. Within reasonable limits, a longer recording time will improve the chance of recording an abnormality or abnormalities and of demonstrating their variability. Experience in many centers shows that an absolute minimum of 20 minutes of artifact-free recording (including activation procedures) is necessary to assess baseline EEG activity. Longer recordings are more sensitive to the detection of epileptiform abnormalities and are encouraged.[6,7] The addition of photic stimulation, hyperventilation, and especially sleep (which should be recorded whenever possible) often requires an increase of recording time.

3.8 ^*The recordings should include periods when the eyes are open and when they are closed. Proper EEG recordings require examining the effect of stimuli on the EEG. A comparison between the eyes-open and eyes-closed condition constitutes one important means for assessment. Some rhythms can be masked by the alpha activity and are visible only when the alpha rhythm has been attenuated by eye-opening. Certain forms of eye movement may appear to be frontal delta or theta activity,

but eye-opening and closing helps in differentiation. Finally, paroxysmal activity may appear only when the eyes are opened or only when the eyes are closed or at the times these conditions change. Thus, failure to record with eye-opening and closing as a routine procedure can reduce chances of obtaining potentially important information. This procedure is so simple that it is unjustifiable not to request eye-opening and closure whenever patient cooperation permits or to manually open and close the eyes when it does not.

Photic stimulation should be performed in a room with dimmed lighting using a lamp placed at least 30 cm from the patient's face. Photic stimulation should be performed before hyperventilation or at least 3 minutes after hyperventilation, after all hyperventilation-related EEG changes have resolved.

Hyperventilation should be used routinely unless medical or other justifiable reasons (e.g., a recent intracranial hemorrhage, significant cardiopulmonary disease, sickle cell disease or trait, or patient inability or unwillingness to cooperate) contraindicate it. It should be performed for a minimum of 3 minutes, with continued recording for at least 1 minute after cessation of overbreathing. At times, hyperventilation must be performed for a longer period to obtain adequate activation of the EEG. To evaluate the effects of this activation technique, at least 1 minute of recording with the same montage should be obtained before overbreathing begins. The record should contain an assessment of the quality of patient effort during hyperventilation.

A single-channel electrocardiogram (ECG) should be included on one EEG channel. It is often helpful if spikes and sharp waves, or pulse or ECG artifact, are in question.

Photic stimulation and hyperventilation are provocative maneuvers intended to elicit epileptiform discharges, and potentially seizures, in susceptible patients. Patients and caregivers should be informed of this possibility in advance.

3.9 ˆ*Sleep recordings should be performed whenever possible, but not to the exclusion of the waking record. Considerable additional information can be obtained by recording during drowsiness and sleep, especially about epileptiform discharges.[8,9] Some laboratories use sleep recording routinely. Sleep recording is usually essential for patients with suspected or known seizure disorders.

Sleep deprivation may be used to increase the yield of EEGs.[10,11] In patients with epilepsy, sleep deprivation increases the frequency of detection of epileptiform discharges, even during wakefulness.

3.10ˆ*The patient's level of consciousness (awake, drowsy, sleeping, or comatose), and any change thereof, should be noted by the technologist on the EEG recording. Any commands or signals to the patient, and any movement or clinical seizure activity or absence thereof, should also be noted on the recording. Careful observation of the patient with frequent notations is often essential, particularly when unusual waveforms are observed in the tracing. Abbreviations used should be standardized, with their definitions readily available to the reader.

In stuporous or comatose patients and those showing invariant EEG patterns of any kind, visual, auditory, and somatosensory stimuli should be applied systematically during the recording. The stimuli and the patient's responses or failure to respond should be noted in the recording as near as possible to their point of occurrence.

It is the responsibility of the electroencephalographer to recognize the patterns usually associated with different states of consciousness, but observations by the technologist about the patient's clinical status can also be of considerable interpretative value, particularly when discrepancies or unusual correlations occur.

To facilitate assessing awake background activity, it is important for the technologist to ascertain that the patient is maximally alert for at least a portion of the record.

3.11 Special procedures that are of some risk to the patient should be carried out only in the presence of a qualified physician, only in an environment with adequate resuscitation equipment, and with the informed consent of the patient or responsible relative or legal guardian.

3.12 In most situations, the EEG is interpreted by a neurophysiologist after the recording is completed. This should be done in a timely fashion. The technologist should notify the interpreting physician and supervisor for critical results. These include the presence of electrographic or clinical seizures during the record, as well as other significant clinical events.

3.13 EEGs for the evaluation of cessation of cerebral function ("cerebral death") require special procedures and extraordinary precautions (see Guideline 6: *Minimum Technical Standards for EEG Recording in Suspected Cerebral Death*).

3.14 Although not an absolute requirement, simultaneous video recording with the EEG is a useful adjunct and is now routine in many laboratories. This may be useful for interpreting clinical events as well as identifying artifacts. The use of video does not reduce the importance of having an attentive technologist. If video is recorded, institutional policies should be followed regarding the need for consent. Storage and use of the video for any nonclinical purpose (e.g., educational) should also be consistent with institutional policies.

3.15 EEG data should be stored/archived in accordance with institutional and state policies for record retention. Because EEG interpretation has some subjectivity, recordings should be made available when requested by outside physicians.

DISCLAIMER

This statement is provided as an educational service of the American Clinical Neurophysiology Society (ACNS). It is based on an assessment of current scientific and clinical information. It is not intended to include all possible proper methods of care for a particular problem or all legitimate criteria for choosing to use a specific procedure. Neither is it intended to exclude any reasonable alternative methodologies. American Clinical Neurophysiology Society recognizes that specific patient care decisions are the prerogative of the patient and the physician caring for the patient based on all of the circumstances involved. The clinical context section is made available to place the evidence-based guidelines into perspective with current practice habits and challenges. Formal practice recommendations are not intended to replace clinical judgment.

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American Clinical Neurophysiology Society Guideline 2: Guidelines for Standard Electrode Position Nomenclature

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Summary: This revision to the EEG Guidelines is an update incorporating current electroencephalography technology and practice and was previously published as Guideline 5. While the 10-10 system of electrode position nomenclature has been accepted internationally for almost two decades, it has not been used universally. The reasons for this and clinical scenarios when the 10-10 system provides additional localizing information are discussed in this revision. In addition, situations in which AF1/2, AF5/6, PO1/2 and PO5/6 electrode positions may be utilized for EEG recording are discussed.

Key Words: Electroencephalography electrode position, 10-10 System, International 10-20 system, Adult, Pediatric.

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The 10-20 system of electrode placement, proposed by the International Federation of Societies for Electroencephalography and Clinical Neurophysiology in 1958,[1] has been the international standard for recording routine scalp EEG for clinical use. This system provides a consistent and replicable method of recording EEG with 21 electrodes placed at relative distances (10% or 20%) between the cranial landmarks over the head. It has also been used as a standard relative head surface–based positioning method for recording evoked and event-related potentials and for various transcranial brain mapping methods.

The development of multichannel EEG hardware systems and topographic source localization methods has resulted in the availability and frequent use of higher EEG electrode density with improved spatial resolution. Therefore, a modification, termed the 10-10 system, was proposed and accepted as a standard by the American Clinical Neurophysiology Society[2] and the International Federation of Clinical Neurophysiology.[3] This provided nomenclature guidelines for several additional electrodes in the anteroposterior, coronal, and inferior planes.

With the availability of EEG systems capable of recording with a greater number of channels (e.g., 128, 256), there is a need to standardize the placement of additional electrodes. A further extension of the 10-10 system, called the 10-5 system, has been proposed,[4] but not been accepted by the American Clinical Neurophysiology Society or the International Federation of Clinical Neurophysiology.

This guideline describes the method for combining a slight modification of the International 10-20 system with a slight modification of the combinatorial rule, described below in the desirable characteristics, which allows for an extension of the 10-20 system to designate the 10% electrode positions. This extension is designated the 10-10 system. The guideline also discusses the clinical context for the use of the 10-20 and 10-10 systems.

This report is divided into the following sections: (1) desirable characteristics of an alphanumeric nomenclature; (2) head diagram of the "modified combinatorial nomenclature"; (3) explanation of the modification of the 10-20 nomenclature within the modified combinatorial 10-10 system; (4) explanation of the deviation from a strict combinatorial nomenclature in the modified system; (5) extension of combinatorial nomenclature to positions inferior to those demonstrated in Fig. 1; (6) clinical context for use of the two systems. Use of EEG electrode position nomenclature for purposes other than clinical EEG, as well as the proposed 10-5 system will not be discussed further in this study.

I. DESIRABLE CHARACTERISTICS OF AN ALPHANUMERIC NOMENCLATURE

1. The alphabetical part should consist of one but no more than two letters.
2. The letters should be derived from names of underlying lobes of the brain or other anatomic landmarks.
3. The complete alphanumeric term should serve as a system of coordinates, locating the designated electrode according to the following rules.
   a. Each letter should appear on only one coronal line. (In standard 10-20 terminology, the only outstanding exception to this rule are the "T" (temporal) names that appear on both the central and parietal coronal lines. For reasons discussed in the *Explanation of the modification of the 10-20 nomenclature within the modified combinatorial system* section, this exception is replaced by a more consistent terminology within the

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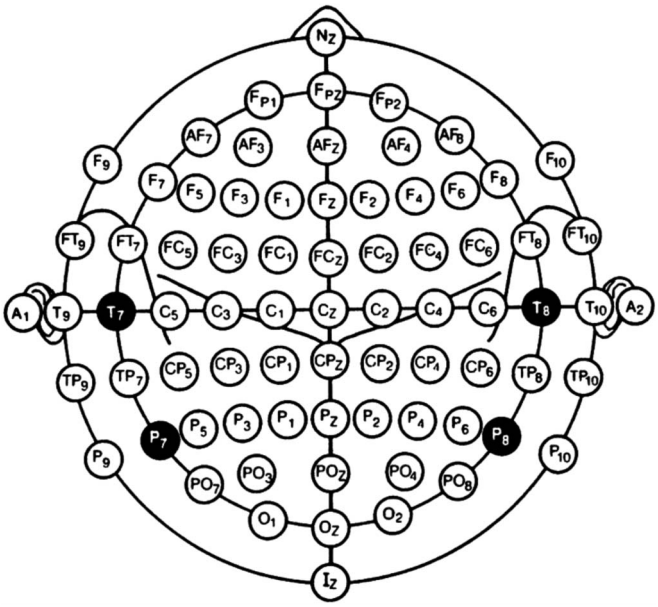

FIG. 1. Modified combinatorial nomenclature for the 10-10 system.

nomenclature. For emphasis, this modification is displayed on the head diagram in the Head diagram of the 10-10 system section with white lettering on a black background.)

b. Each number should designate a sagittal line so the same postscripted number identifies all positions lying on that sagittal line. (Again, the only outstanding exception to this rule in the current 10-20 system is in the "T" numbering. For example, this results in the F7, T3, and T5 designations all appearing on a single sagittal line. This exception is also eliminated within the recommended nomenclature. Once more for emphasis, this modification is displayed in the head diagram in Fig. 1 with white lettering on a black background.)

II. HEAD DIAGRAM OF THE 10-10 SYSTEM

In Fig. 1, the modifications of the current 10-20 terminology, instituted for reasons explained in the next section, are emphasized by displaying them with white lettering on a black background.

III. EXPLANATION OF THE MODIFICATION OF THE 10-20 NOMENCLATURE WITHIN THE MODIFIED COMBINATORIAL SYSTEM

The modified 10-10 terminology replaces the inconsistent T3/T4 and T5/T6 terms with the consistent T7/T8 and P7/P8. The head diagram in Fig. 1 emphasizes consistency of the terms T7/T8 and P7/P8 by showing them with white lettering on black circles. The value of this becomes evident when inspecting the head diagram, which shows that, except for Fpl/Fp2 and O1/O2, all electrode positions along the same sagittal line have the same postscripted number and that all electrodes designated by the same letter(s) lie on the same coronal line. Thus, the alphanumeric nomenclature for each electrode specifies its coordinate location within the 10-20 grid system. Once this is done, the positions *10% inferior* to the standard frontotemporal electrodes are easily designated as F9/Fl0, T9/Tl0, and P9/P10.

As indicated above, the straightforward designation of an electrode's coordinate localization by its nomenclature requires replacement of the inconsistent T3/4 by T7/8, which is a readily understandable modification. A more radical modification replaces T5/6 by P7/8. However, even with this more radical departure, P can be recognized as representing parietal when it is associated with a postscripted number with a value of 6 or less, whereas it can be recognized as implying posterior temporal if P is associated with a number with a value of 7 or greater.

However, even though T7/8 and P7/8 in the head diagram *emphasize the internally consistent logic* of the system, it would clearly be *an acceptable alternative* to continue to use T3/4 and T5/6 without detracting from the logic of the remaining system.

IV. EXPLANATION OF THE DEVIATION FROM A STRICT COMBINATORIAL NOMENCLATURE IN THE MODIFIED SYSTEM PROPOSED HEREIN

The 10-20 system does not name electrode positions forming the four 10% intermediate coronal lines lying between the five standard coronal lines containing currently named electrode positions. The strict combinatorial system designates the currently unnamed positions by combining the names or letters for the two standard electrode positions that surround a currently undesignated 10% intermediate electrode position.

Thus, positions in the second intermediate coronal line are designated as either the frontotemporal positions (FT) or the frontocentral positions (FC), depending on their location as noted in the head diagram.

The electrode positions in the third intermediate coronal line are designated as temporal-posterior temporal (TP) or centroparietal (CP) as noted in Fig. 1.

The positions in the fourth and final intermediate coronal line are designated as posterior temporo-occipital (PO) or parieto-occipital (PO).

The *only proposed deviation* from the strict combinatorial rule discussed above is in naming the first intermediate transverse positions as anterior frontal (AF) electrodes rather than frontopolar-frontal electrodes. The latter terminology would designate the electrodes with either three letters (FpF) or the same two letters (FF). Since neither of these letter designations is desirable (the first because it uses three letters and the second because it uses the same letter twice), the Committee proposed using the readily understandable anterior frontal (AF) designation displayed in Fig. 1.

Once the above letters are assigned to the currently unnamed 10% intermediate positions, then their alphanumeric designation is completed by postscripting the letters assigned to an electrode by the number designating the sagittal line on which the electrode

lies. For example, in Fig. 1, AF3, FC3, CP3, and PO3 all lie on the same sagittal line designated by the number 3.

As noted in Fig. 1, only one electrode position is placed between AFz and AF7 (AF3) and between AFz and AF8 (AF4). Similarly, there is only one electrode between POz and PO7 (PO3) and between POz and PO8 (PO4). Because of the short anatomic distance between the two points, placing additional electrodes (such as AF1/2, AF5/6, PO1/2, PO5/6), would result in excessive crowding and may be clinically impractical. However, they could be used in patients with large head sizes if clinically feasible and necessary.

When this is done, each new alphanumeric designation is not only directly related to a slight modification of the 10-20 terminology but also serves as an internally consistent coordinate system that locates each newly designated electrode position at the intersection of a specified coronal (identified by the prefixed letter) and sagittal (identified by the postfixed number) line.

V. EXTENSION OF THE 10-10 COMBINATORIAL NOMENCLATURE TO POSITIONS INFERIOR TO THOSE DEMONSTRATED IN FIGURE 1

Positions posterior to electrodes displayed in the ninth and tenth rows would be designated as PO9 (10% inferior to PO7), PO10 (10% inferior to PO8), O9 (10% inferior to O1), and O10 (10% inferior to O2). Electrodes 10% inferior to the ninth row would be designated with the postscripted number 11 (F11, FT11, T11, TPl1, P11, PO11, and O11), and those 10% inferior to the tenth row would be designated with a postscripted number 12 (F12, FT12, T12, TPl2, P12, and O12).

VI. CLINICAL CONTEXT

The additional, more closely spaced electrodes in the 10-10 system clearly provide better spatial resolution, but there are some practical concerns with its routine use for all EEGs. Placement of several additional electrodes requires increased time and effort on the part of technologists, potentially reducing the number of studies that can be performed in a day. Additional electrodes need to be purchased. Routine EEGs are ordered or recorded for a variety of indications, and it is not clear whether the extra electrodes provide clinically meaningful additional information in situations where localization of an epileptiform abnormality is not critical (for instance, in patients with encephalopathy or other generalized abnormalities). Also, most vendors of commercial EEG machines in the United States continue to provide headboxes with electrode positions and nomenclature limited to the 10-20 system. A commitment from the vendors to switch to the 10-10 system would be necessary to promote universal use of the 10-10 system for all EEG studies.

The change in nomenclature from T3/T4 and T5/T6 to T7/T8 and P7/P8 is essentially a conceptual one. However, one does not intuitively think of P7/P8 electrodes as overlying the temporal region rather than the parietal region. Although this is consistent with the logic proposed in the 10-10 system, it appears to be contrary to one of the desirable characteristics of an alphanumeric nomenclature (the letter should indicate the underlying lobe of the brain). *It should be emphasized to trainees that P represents parietal when it is associated with a postscripted number with a value of 6 or less and implies posterior temporal if P is associated with a number with a value of 7 or greater.* Also, EEG machine vendors would need to change the labeling of electrodes in headboxes.

Nevertheless, the additional electrodes included in the 10-10 system can be very useful in certain clinical situations. During long-term video-EEG studies of patients undergoing presurgical evaluation, they can provide more precise localizing information with regard to interictal epileptiform discharges and ictal EEG onsets. In patients with suspected temporal lobe epilepsy, the limitations of the 10-20 system for precise localization have been recognized for several decades, leading to the use of additional noninvasive (T1/T2 electrode positions proposed by Silverman) and semi-invasive electrodes (nasopharyngeal, sphenoidal). Use of the temporal electrode positions described in the 10-10 system (FT7/FT8, FT9/FT10, T9/T10) can be particularly helpful in such patients and may obviate the need for T1/T2 electrodes. Despite being measured in different ways, the positions of FT9/FT10 electrodes closely approximate those of T1/T2 electrodes. Although some controversy persists, several studies have suggested that anterior temporal electrodes detect interictal and ictal epileptiform abnormalities virtually as well as do sphenoidal electrodes. They also provide more consistent recording information, do not result in pain and discomfort for patients and do not require physician expertise.[5] Nasopharyngeal leads provide less information, are uncomfortable for patients, and are prone to artifacts and therefore should be avoided for routine clinical use.[6] Similarly, in patients with mesial frontal lobe epilepsy, some of the electrodes from the 10-10 system (FC1/FC2, FCz, C1/C2, CP1/CP2, and CPz) in addition to the 10-20 system may be helpful to best delineate the epileptic focus. Other electrode positions could be used selectively in other types of focal epilepsies as well, but the entire set of electrodes described in the 10-10 system may not always be necessary even for presurgical video-EEG monitoring.

Using all of the >70 electrode positions described in the 10-10 system, and even additional electrode positions, is likely to be of greatest value when advanced digital studies, such as source localization and electrical source imaging, are performed in addition to standard visual analysis of the EEG.

RECOMMENDATIONS

Although the decision regarding use of appropriate electrode positions should be individualized depending on the clinical need in a given patient, taking all of the factors discussed above into consideration, a reasonable clinical approach would be as follows:

1. For routine EEGs, where the indication is not epilepsy or localization of an epileptic focus is not critical, the 10-20 system may be clinically adequate for most patients and efficient in terms of time, effort, and cost. It may also be sufficient for many diagnostic (such as distinguishing between epileptic and psychogenic events) long-term ambulatory and inpatient video-EEG monitoring studies.

2. Because of its greater spatial resolution, the 10-10 system provides better localizing information and should be used in patients undergoing presurgical evaluation in the epilepsy monitoring unit. However, not all of the electrode positions need be used; selective electrode positions can be chosen based on the suspected location of the epileptic focus. Additional electrodes from the 10-10 system may also be used sometimes during routine EEGs, when an attempt is made to localize the epileptic focus in patients with suspected focal epilepsy, and during certain diagnostic ambulatory and video-EEG studies (for instance, in patients with psychogenic events versus frontal lobe seizures).
3. The entire set of 10-10 electrode positions, with or without additional electrodes, can be used if additional digital analysis, including source localization and electrical source imaging, is planned.
4. Although it would be desirable to switch to T7/T8 and P7/P8 for both clinical and educational (including publication) purposes, it would be an acceptable alternative to continue to use T3/4 and T5/6, or to use both terms, at present. Modification of commercially available EEG machine head-boxes to reflect the change and education of trainees will likely lead to gradual acceptance of the new terminology.

DISCLAIMER

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GUIDELINE

American Clinical Neurophysiology Society Guideline 3: A Proposal for Standard Montages to Be Used in Clinical EEG

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Summary: This revision to the EEG Guidelines is an update incorporating current electroencephalography technology and practice and was previously published as Guideline 6. A discussion of methodology for the appropriate selection of reference electrodes is added. In addition, montages are added to assist with localization of abnormal activity in mesial frontal and anterior temporal regions.

Key Words: Electroencephalography montage, 10-10 system, International 10-20 system, Adult, Pediatric.

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Montages are logical and orderly arrangements of channels (electrode pairs, with waveforms representing the potential difference between the two electrodes) that display EEG activity over the entire scalp, allow comparison of activity on the two sides of the brain (lateralization), and aid in localization of recorded activity to a specific brain region. With 21 electrode positions in the 10-20 system and 16 channels, the number of possible montages is 21.[16] The 10-10 system, with more than 70 electrode positions, and the ability to display up to 256 channels in modern digital EEG machines, provides the ability to create an even greater number of montages. However, from a clinical and practical standpoint, only a limited number of montages need to be used during a recording session.

A great diversity of montages exists among different EEG laboratories, but many of these montages fail to display the EEG adequately or are inordinately complex. Moreover, this diversity impedes interchange of information among electroencephalographers, to the ultimate detriment of patient care.

Recognizing the need for improving this aspect of EEG practice, the montages listed in this Guideline are recommended for standard use by clinical laboratories. This proposal should not be construed as an attempt to limit the total number of montages used by any EEG laboratory. Indeed, depending on individual recording circumstances, additional montages may be necessary for an adequate EEG examination and for the solution of particular problems. The proposed montages are intended to constitute a basic minimum, not a maximum, for general-purpose use. If these recommendations are adopted widely, communication among electroencephalographers should be facilitated.

Montages using additional electrode positions described in the 10-10 system are particularly useful during video-EEG monitoring, especially in patients with suspected temporal or frontal lobe epilepsy, but can also be helpful for routine EEG recording. This Guideline provides some suggested montages for use in these situations.

However, the proposed montages are not designed for other special purposes, such as for neonatal EEGs, all-night sleep recordings, or for verification of electrocerebral inactivity.

1. Montage Designations

1.1 The class of montage is designated as follows: longitudinal bipolar (LB), transverse bipolar (TB), or referential (R). (Bipolar derivations are also sometimes called "differential").

1.2 The numeral to the left of the point indicates the number of channels. Montages are designed for 16, 18, and 20 channels.

1.3 The numeral two or three to the right of the point indicates an alternative montage of the same class for a particular size of instrument (e.g., LB-16.2 and LB-16.3 are alternative for LB-16.1). The number of alternatives has been limited to a maximum of three.

2. Recommendations Governing Selection of the Proposed Montages with Explanatory Notes

2.1 The Committee *reaffirms* the statements pertaining to montages set forth previously in the Guidelines of the American Clinical Neurophysiology Society (ACNS) and that are paraphrased as follows:

(a) that no less than 16 channels of simultaneous recording be used, and that a larger number of channels be encouraged,

(b) that the full 21 electrode placements of the 10-20 system be used,

(c) that both bipolar and referential montages be used for clinical interpretation,

(d) that the electrode derivations of each channel be clearly identified at the beginning of each montage,

(e) that the pattern of electrode connections be made as simple as possible, and that montages should be easily comprehended,

(f) that the electrode pairs (bipolar) preferentially should run in straight (unbroken) lines and the interelectrode distances kept equal,

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(g) that tracings from the more anterior electrodes be placed above those from the more posterior electrodes on the recording page, and
(h) that it is very desirable to have some of the montages comparable for all EEG laboratories.

In addition, a single channel electrocardiogram (ECG) should be included on one EEG channel. This is helpful to distinguish between epileptiform discharges and ECG artifact, and to identify pulse artifact.

2.2 The Committee recommends a "left above right" order of derivations, i.e., on the recording page, left-sided leads should be placed above right-sided leads for either alternating pairs of derivations or blocks of derivations. This recommendation coincides with the prevailing practice of most EEG laboratories, at least in North America and in many other areas.
2.3 A maximum number of electrodes should be represented in each montage, within limitations imposed by the number of recording channels, to ensure adequate coverage of head areas.
2.4 Three classes of montage should be represented in each recording in the following: LB, TB, and R.
2.5 For 16- and 18-channel recording, one montage from each of the 3 classes will be needed (Table 1).
2.6 If 20 channels are available, 2 channels of polygraphic variables may be added to the 18-channel bipolar montages, and a reference to Cz in between those to Fz and Pz.

For adequate mapping of electrical fields, additional montages may need to be devised that include LB and TB chains recorded simultaneously.

In the montages listed for R recording, mastoid leads may be substituted for A1 and A2 and can be designated as Ml and M2.

Potential pitfalls in referential recording are numerous, and caution should be exercised if unwanted activity appears in a reference lead. In such instances, another reference should be chosen, and the change should be clearly noted in the recording. Common alternative choices of reference include Cz and an average constructed from all electrodes on the head. In average reference recording, the prefrontal electrodes, Fp1 and Fp2, and anterior temporal electrodes, F7 and F8, are often omitted from the average to reduce contamination by eye movement artifact.

2.7 A logical order of arrangement should prevail in each montage and in comparable montages designed for instruments of different sizes.

Recognizing the fact that experienced electroencephalographers differ for valid reasons in their approach to the display of EEG activity, alternative sets of montages have been included in the recommendations. Further details about the principles of montage design and the different preferences by members of this Committee have been published (*Am J EEG Technol*, 17: Nos. 1 and 2, 1977).

In general, the LB.1 and the R.1 series consist of leads grouped in anatomical proximity extending sequentially across the head from left to right. In this system, hemispheric differences are readily appreciated. In the LB.2 and LB.3 series, blocks of homologous derivations are compared (LB.2 extending from the midline sagittal region laterally, LB.3 extending from lateral regions medially). The alternative montages in the TB series depend, in part, on the extent of polar coverage. In the R.2 and R.3 series, homologous derivations are juxtaposed in adjacent channels to facilitate comparison of localized regions (R.2 extending from the midline sagittal region laterally and R.3 extending from the lateral regions medially).

Regarding referential montages, the choice of reference is critically important. A midline electrode (such as Cz) would be a better choice of reference than A1 or A2 if temporal lobe epilepsy is suspected, as the field of a temporal epileptiform discharge often involves A1 or A2 (see the suggested Cz referential montages in Appendix 6 below). Also, A1/A2 electrodes tend to be frequently contaminated with artifact. However, a Cz reference would not be a good choice if there is prominent sleep activity or abnormalities are noted predominantly in sleep. An ear reference would be more suitable than Cz in the delineation of a frontal focus.

Minor modifications of the recommended montages may be instituted during part of the recording, especially for monitoring other physiologic variables (such as tremor or respiration), if the modifications do not infringe on the principles set forth in these recommendations.

When electrode positions from the 10-10 system or sphenoidal electrodes are used in the recording, either bipolar or referential montages can be used. If only selected electrode positions from the 10-10 system (such as FT9/FT10 or FC1/FC2) are added to the 10-20 system, instead of the entire set of 10-10 electrodes, it may result in unequal interelectrode distances. Nevertheless, bipolar montages can provide valuable localizing information. For instance, F7/F8 electrodes record activity from both anterior temporal and frontal regions. A bipolar montage using FT9/FT10 (or sphenoidal electrodes) can localize activity more precisely to the anterior temporal region (see the suggested anterior temporal montages in Appendix 2 below). Similarly, montages that include closely spaced parasagittal electrodes (FC1/FC2, FCz, C1/C2, CP1/CP2, and CPz) can be very helpful in patients with suspected mesial frontal lobe epilepsy (see the suggested transverse frontal montage in Appendix 4 below).

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TABLE 1. Number of Montages Recommended

No. Channels	Longitudinal Bipolar	Transverse Bipolar	Referential	Total
20	1 (3)	1 (2)	1 (3)	3
18	1 (3)	1 (2)	1 (3)	3
16	1 (3)	1 (3)	1 (3)	3

Figures in parentheses refer to the number of alternative montages proposed.

APPENDIX 1. Standard Longitudinal Bipolar (LB) Montages*

Channel No.	LB-18.1	LB-18.2	LB-18.3	LB-16.1	LB-16.2	LB-16.3
1	Fp1-F7	Fz-Cz	Fp1-F7	Fp1-F7	Fp1-F3	Fp1-F7
2	F7-T7 (T3)	Cz-Pz	F7-T7 (T3)	F7-T7 (T3)	F3-C3	F7-T7 (T3)
3	T7 (T3)-P7 (T5)	Fp1-F3	T7 (T3)-P7 (T5)	T7 (T3)-P7 (T5)	C3-P3	T7 (T3)-P7 (T5)
4	P7 (T5)-O1	F3-C3	P7 (T5)-O1	P7 (T5)-O1	P3-O1	P7 (T5)-O1
5	Fp1-F3	C3-P3	Fp2-F8	Fp1-F3	Fp2-F4	Fp2-F8
6	F3-C3	P3-O1	F8-T8 (T4)	F3-C3	F4-C4	F8-T8 (T4)
7	C3-P3	Fp2-F4	T8 (T4)-P8 (T6)	C3-P3	C4-P4	T8 (T4)-P8 (T6)
8	P3-O1	F4-C4	P8 (T6)-O2	P3-O1	P4-O2	P8 (T6)-O2
9	Fz-Cz	C4-P4	Fp1-F3	Fp2-F4	Fp1-F7	Fp1-F3
10	Cz-Pz	P4-O2	F3-C3	F4-C4	F7-T7 (T3)	F3-C3
11	Fp2-F4	Fp1-F7	C3-P3	C4-P4	T7 (T3)-P7 (T5)	C3-P3
12	F4-C4	F7-T7 (T3)	P3-O1	P4-O2	P7 (T5)-O1	P3-O1
13	C4-P4	T7 (T3)-P7 (T5)	Fp2-F4	Fp2-F8	Fp2-F8	Fp2-F4
14	P4-O2	P7 (T5)-O1	F4-C4	F8-T8 (T4)	F8-T8 (T4)	F4-C4
15	Fp2-F8	Fp2-F8	C4-P4	T8 (T4)-P8 (T6)	T8 (T4)-P8 (T6)	C4-P4
16	F8-T8 (T4)	F8-T8 (T4)	P4-O2	P8 (T6)-O2	P8 (T6)-O2	P4-O2
17	T8 (T4)-P8 (T6)	T8 (T4)-P8 (T6)	Fz-Cz	ECG	ECG	ECG
18	P8 (T6)-O2	P8 (T6)-O2	Cz-Pz			
19	ECG	ECG	ECG			

*10-10 electrode position nomenclature with 10-20 nomenclature in parentheses.

APPENDIX 2. Standard Transverse Bipolar (TB) Montages*

Channel No.	TB-18.1	TB-18.2	TB-16.1	TB-16.2	TB-16.3
1	F7-Fp1	Fp1-Fp2	F7-Fp1	Fp1-Fp2	F7-Fp1
2	Fp1-Fp2	F7-F3	Fp1-Fp2	F7-F3	Fp2-F8
3	Fp2-F8	F3-Fz	Fp2-F8	F3-Fz	F7-F3
4	F7-F3	Fz-F4	F7-F3	Fz-F4	F3-Fz
5	F3-Fz	F4-F8	F3-Fz	F4-F8	Fz-F4
6	Fz-F4	A1-T7 (T3)	Fz-F4	A1-T7 (T3)	F4-F8
7	F4-F8	T7 (T3)-C3	F4-F8	T7 (T3)-C3	T7 (T3)-C3
8	T7 (T3)-C3	C3-Cz	T7 (T3)-C3	C3-Cz	C3-Cz
9	C3-Cz	Cz-C4	C3-Cz	Cz-C4	Cz-C4
10	Cz-C4	C4-T8 (T4)	Cz-C4	C4-T8 (T4)	C4-T8 (T4)
11	C4-T8 (T4)	T8 (T4)-A2	C4-T8 (T4)	T8 (T4)-A2	P7 (T5)-P3
12	P7 (T5)-P3	P7 (T5)-P3	P7 (T5)-P3	P7 (T5)-P3	P3-Pz
13	P3-Pz	P3-Pz	P3-Pz	P3-Pz	Pz-P4
14	Pz-P4	Pz-P4	Pz-P4	Pz-P4	P4-P8 (T6)
15	P4-P8 (T6)	P4-P8 (T6)	P4-P8 (T6)	P4-P8 (T6)	P7 (T5)-O1
16	P7 (T5)-O1	O1-O2	O1-O2	O1-O2	O2-P8 (T6)
17	O1-O2	Fz-Cz	ECG	ECG	ECG
18	O2-P8 (T6)	Cz-Pz			
19	ECG	ECG			

*10-10 electrode position nomenclature with 10-20 nomenclature in parentheses.

APPENDIX 3. Standard Referential Montages—Ear Reference*

Channel No.	R-18.1	R-18.2	R-18.3	R-16.1	R-16.2	R-16.3
1	F7-A1	Fz-A1	F7-A1	F7-A1	Fp1-A1	F7-A1
2	T7 (T3)-A1	Pz-A1	F8-A2	T7 (T3)-A1	Fp2-A2	F8-A2
3	P7 (T5)-A1	Fp1-A1	T7 (T3)-A1	P7 (T5)-A1	F3-A1	T7 (T3)-A1
4	Fp1-A1	Fp2-A2	T8 (T4)-A2	Fp1-A1	F4-A2	T8 (T4)-A2
5	F3-A1	F3-A1	P7 (T5)-A1	F3-A1	C3-A1	P7 (T5)-A1
6	C3-A1	F4-A2	P8 (T6)-A2	C3-A1	C4-A2	P8 (T6)-A2
7	P3-A1	C3-A1	Fp1-A1	P3-A1	P3-A1	Fp1-A1
8	O1-A1	C4-A2	Fp2-A2	O1-A1	P4-A2	Fp2-A2
9	Fz-A1	P3-A1	F3-A1	Fp2-A2	O1-A1	F3-A1
10	Pz-A2	P4-A2	F4-A2	F4-A2	O2-A2	F4-A2
11	Fp2-A2	O1-A1	C3-A1	C4-A2	F7-A1	C3-A1
12	F4-A2	O2-A2	C4-A2	P4-A2	F8-A2	C4-A2
13	C4-A2	F7-A1	P3-A1	O2-A2	T7 (T3)-A1	P3-A1
14	P4-A2	F8-A2	P4-A2	F8-A2	T8 (T4)-A2	P4-A2
15	O2-A2	T7 (T3)-A1	O1-A1	T8 (T4)-A2	P7 (T5)-A1	O1-A1
16	F8-A2	T8 (T4)-A2	O2-A2	P8 (T6)-A2	P8 (T6)-A2	O2-A2
17	T8 (T4)-A2	P7 (T5)-A1	Fz-A1	ECG	ECG	ECG
18	P8 (T6)-A2	P8 (T6)-A2	Pz-A2			
19	ECG	ECG	ECG			

*10-10 electrode position nomenclature with 10-20 nomenclature in parentheses.

APPENDIX 4. Suggested Longitudinal Bipolar Anterior Temporal (LBAT) Montages*

Channel No.	LBAT 20.1	LBAT 20.2	LBAT 20.3
1	Fp1-F7	Fz-Cz	Fp1-F7
2	†F7-FT9	Cz-Pz	†F7-FT9
3	†FT9-T7 (T3)	Fp1-F3	†FT9-T7 (T3)
4	T7 (T3)-P7 (T5)	F3-C3	T7 (T3)-P7 (T5)
5	P7 (T5)-O1	C3-P3	P7 (T5)-O1
6	Fp1-F3	P3-O1	Fp2-F8
7	F3-C3	Fp2-F4	†F8-FT10
8	C3-P3	F4-C4	†FT10-T8 (T4)
9	P3-O1	C4-P4	T8 (T4)-P8 (T6)
10	Fz-Cz	P4-O2	P8 (T6)-O2
11	Cz-Pz	Fp1-F7	Fp1-F3
12	Fp2-F4	†F7-FT9	F3-C3
13	F4-C4	†FT9-T7 (T3)	C3-P3
14	C4-P4	T7 (T3)-P7 (T5)	P3-O1
15	P4-O2	P7 (T5)-O1	Fp2-F4
16	Fp2-F8	Fp2-F8	F4-C4
17	†F8-FT10	†F8-FT10	C4-P4
18	†FT10-T8 (T4)	†FT10-T8 (T4)	P4-O2
19	T8 (T4)-P8 (T6)	T8 (T4)-P8 (T6)	Fz-Cz
20	P8 (T6)-O2	P8 (T6)-O2	Cz-Pz
21	ECG	ECG	ECG

*10-10 electrode position nomenclature with 10-20 nomenclature in parentheses.
†Alters interelectrode distance.

APPENDIX 5. Suggested Transverse Frontal Montage*

1. Fp1-Fp2
2. F7-F3
3. F3-Fz
4. Fz-F4
5. F4-F8
6. †FC1-FCz
7. †FCz-FC2
8. T7 (T3)-C3
9. †C3-C1
10. †C1-Cz
11. †Cz-C2
12. †C2-C4
13. C4-T8 (T4)
14. †CP1-CPz
15. †CPz-CP2
16. P7 (T5)-P3
17. P3-Pz
18. Pz-P4
19. P4-P8 (T6)
20. O1-O2
21. ECG

*10-10 electrode position nomenclature with 10-20 nomenclature in parentheses.
†Alters interelectrode distance.

APPENDIX 6. Suggested Referential Montages—Cz Reference*

Channel No.	R-18.1	R-18.2	R-18.3	R-16.1	R-16.2	R-16.3
1	F7-Cz	Fz-Cz	F7-Cz	F7-Cz	Fp1-Cz	F7-Cz
2	T7 (T3)-Cz	Pz-Cz	F8-Cz	T7 (T3)-Cz	Fp2-Cz	F8-Cz
3	P7 (T5)-Cz	Fp1-Cz	T7 (T3)-Cz	P7 (T5)-Cz	F3-Cz	T7 (T3)-Cz
4	Fp1-Cz	Fp2-Cz	T8 (T4)-Cz	Fp1-Cz	F4-Cz	T8 (T4)-Cz
5	F3-Cz	F3-Cz	P7 (T5)-Cz	F3-Cz	C3-Cz	P7 (T5)-Cz
6	C3-Cz	F4-Cz	P8 (T6)-Cz	C3-Cz	C4-Cz	P8 (T6)-Cz
7	P3-Cz	C3-Cz	Fp1-Cz	P3-Cz	P3-Cz	Fp1-Cz
8	O1-Cz	C4-Cz	Fp2-Cz	O1-Cz	P4-Cz	Fp2-Cz
9	Fz-Cz	P3-Cz	F3-Cz	Fp2-Cz	O1-Cz	F3-Cz
10	Pz-Cz	P4-Cz	F4-Cz	F4-Cz	O2-Cz	F4-Cz
11	Fp2-Cz	O1-Cz	C3-Cz	C4-Cz	F7-Cz	C3-Cz
12	F4-Cz	O2-Cz	C4-Cz	P4-Cz	F8-Cz	C4-Cz
13	C4-Cz	F7-Cz	P3-Cz	O2-Cz	T7 (T3)-Cz	P3-Cz
14	P4-Cz	F8-Cz	P4-Cz	F8-Cz	T8 (T4)-Cz	P4-Cz
15	O2-Cz	T7 (T3)-Cz	O1-Cz	T8 (T4)-Cz	P7 (T5)-Cz	O1-Cz
16	F8-Cz	T8 (T4)-Cz	O2-Cz	P8 (T6)-Cz	P8 (T6)-Cz	O2-Cz
17	T8 (T4)-Cz	P7 (T5)-Cz	Fz-Cz	ECG	ECG	ECG
18	P8 (T6)-Cz	P8 (T6)-Cz	Pz-Cz			
19	ECG	ECG	ECG			

*10-10 electrode position nomenclature with 10-20 nomenclature in parentheses.

GUIDELINE

American Clinical Neurophysiology Society Guideline 4: Recording Clinical EEG on Digital Media

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Summary: Digital EEG recording systems are now widely available and relatively inexpensive. They offer multiple advantages over previous analog/paper systems, such as higher fidelity recording, signal postprocessing, automated detection, and efficient data storage. This document provides guidance for the creation of digital EEG recordings including (1) documentation of patient information, (2) notation of information during the recording, (3) digital signal acquisition parameters during the recording, (4) storage of digital information, and (5) display of digital EEG signals.

Key Words: electroencephalography, EEG, guideline, digital recording.

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Digital EEG recording systems are now widely available and relatively inexpensive. They offer multiple advantages over previous analog/paper systems, such as higher fidelity recording, signal postprocessing, automated detection, and efficient data storage. Unlike previous analog EEG recordings, digital EEG acquisition allows the reviewer to view the EEG record with control over the montage, filter settings, gain, and horizontal scaling (seconds of EEG recording viewed per screen page). In hospitals that offer continuous monitoring, digital video-EEG recordings can be streamed directly to a central server for secure, HIPPA compliant storage and review at remote sites.

PATIENT INFORMATION

The electronically recorded information should include the patient's name and date of birth, date on which the test was run, and relevant patient and laboratory identification numbers. Preferably, the EEG report will be stored and merged with the EEG signal after review of the record by a physician. Correction of errors or omissions in the patient-identifying information should also be possible after the recording.

NOTATION OF INFORMATION DURING THE EEG RECORDING

Calibration signals should be recorded at the beginning of each recording, in the manner already conventional for EEG (See Guideline 1, section 3.2). The time of day should be recorded along with the EEG data and any other information that could be used for finding events in the stored record. The recording itself should contain all of the technologist's comments. The technologist should be able to enter event codes and comments even after the EEG recording has been completed. Codes recorded with the data can represent common events such as eyes closure or eye opening; the beginning and the end of hyperventilation; details of photic stimulation; and notation of the patient's alert, drowsy, or asleep state. It should also be possible to enter free-text comments which are then stored along with the EEG data. In addition, there should be provisions for automatically recording information such as impedance values, sampling frequency, filter settings, gain, montage selections, and other technical amplifier control settings at the start of the recording. Any changes made during the recording should be recorded immediately with the EEG data.

RECORDING

Acquisition of EEG data onto a digital storage medium should occur at a minimum sampling rate of 256 samples per second. This is selected to be more than three times the high-frequency filter setting, assuming a typical 70-Hz high filter setting. Higher rates, such as 512 Hz, are preferable to prevent aliasing on modern high-resolution computer screens. Also, because automated detection algorithms are becoming a standard feature of many EEG acquisition systems, higher sampling rates are preferred. Digitization should use a resolution of at least 16 bits per sample including any sign bit. Most modern clinical EEG amplifiers record with a bit depth of 24. A resolution of 16 or more bits is preferable; this allows for an EEG resolution down to 0.05 μV while recording potentials up to plus-or-minus several millivolts without clipping. For example, with a 0.05-μV resolution and a 16-bit analog-to-digital conversion, the maximum allowed excursion would be ± 1.638 mV. This is the dynamic range of the system. Interchannel crosstalk should be less than 1%, i.e., 40 dB down or better. Common mode rejection ratio should be at least 90 dB (and preferably higher) for each of the channels. Additional noise in the recording should be less than 1 μV peak to

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peak at any frequency 0.5 to 100 Hz, including at 60 Hz. Ideally, video recording should be synchronized with the EEG to facilitate review, especially for identification of artifacts and clinical events.

RECORDING STORAGE

Currently, nonerasable and erasable optical storage devices are acceptable for the storage of outpatient routine, 1 hour, 6-hour video-EEG, and ambulatory EEG recordings. For optical storage, digital EEG systems should use widely supported types of storage media (e.g., CD-ROM, DVD-ROM, Blue Ray Recordable [BD-R] or Blue Ray Disc Recordable Erasable [BD-RE]), but optical storage devices are not recommended. This is not only because optical discs can be easily damaged, but also because the optical disc medium is likely to disappear over the next few years. As with floppy disk recordings of the 1990s, newer computers will probably lose the ability to read optical discs in the near future, making it difficult to view these EEG recordings. Newer storage technologies such as USB flash drives and network access servers are inexpensive, more reliable, and practical for even a small neurology practice. For inpatient long-term recordings lasting 24 hours or more, storage on a digital server system is recommended; this can facilitate review in remote locations and backup by hospital IT staff. Storage of video-EEG data on business-grade server storage solutions minimizes the chance of data loss by incorporating built-in data storage redundancy and regular data backup. Additionally, using a server storage solution enables full Health Insurance Portability and Accountability Act (HIPAA) compliance because it can record a full audit trail of every person who accesses the patient record.

The EEG recording formats should be able to store not only the EEG signal data but also the technologist's comments and event codes (for evoked potentials and other events). For research purposes, manufacturers should provide a method for outputting copies of the recording with patient identifiers removed. The EEG recording systems should be able to input and output nonproprietary publicly available data formats (such as European Data Format [EDF] or EDF-plus) for storage of EEG data, so that other manufacturers or third-party software vendors can read the EEG record or translate it into a format readable by another manufacturer's equipment. Manufacturers should provide a method for outputting studies in their format with a stand-alone viewer so that the recording can be viewed by a user on any computer. Manufacturers should also guarantee that newer reader systems can still read older data recorded by the equipment of that manufacturer, even when those data are no longer compatible with current reading systems. This could be accomplished if manufacturers provide a service to their customers to convert all of their older media and files to the current format, and if EEG laboratories remain aware of deteriorating legibility or technical obsolescence of older recordings and ensure that they are converted when necessary. Manufacturers should also inform customers in a timely fashion of the need to convert their data files to maintain legibility. There is uncertainty regarding the availability of commercial digital EEG review devices to replay the stored EEG years into the future, given changes in EEG recording formats. The present lack of a format standard for digital video-EEG recording frequently results in incompatibility between various commercially available devices and may lead to the impossibility of reading and repair of past EEG recordings. Note is made of the existence of statutes governing medical records in each of the individual states, and the existence of local or hospital statutes regarding EEG record storage. These govern the duration of storage, and in some instances, they may also dictate whether magnetic or optical storage is allowed.

DISPLAY

A recording system for clinical use should have the capability to review recorded EEG data on the computer screen with sufficient temporal and spatial resolution. A standard horizontal scaling should be available in which 1 second occupies between 25 and 35 mm, with a minimum resolution of 128 data points/second on the screen for a 10-second page, requiring a horizontal resolution of at least 1,280 pixels. Other more compressed and more expanded horizontal scales should also be available, including scaling differing from the standard by a factor of 2, e.g., 7.5, 15, 30, or 60 mm/second. Vertically, appropriate channel spacing between the baseline of each channel depends on the number of channels displayed. A standard vertical scaling with a minimum spacing of 10 mm per channel should be used for a display of up to 21 channels. Other choices for vertical scaling may be provided as well. Larger gaps can be introduced where necessary to separate blocks of channels and increase readability. Occasional overlap of data between channels is acceptable. The horizontal and vertical scales on the screen should be indicated on the display. For purposes of comparison between different devices, important considerations are the maximum number of channels and the maximum number of seconds that can be displayed on a single screen, using the standard scaling as defined above. *Post hoc* digital filtering should also be available. Control of filter settings should be provided for each individual channel. The system should allow simultaneous display of multiple segments of EEG, allowing side-by-side visual comparison of different segments within one recording and different segments from different recordings obtained on different days. Although many digital EEG review systems may display results of EEG processing such as trending or automated detections, the reviewer should always be given easy access to view the raw EEG data.

Montages available for review should be consistent with those in standard use in the laboratory and with the American Clinical Neurophysiology Society (ACNS) recommendations (see Guideline 3), preferably allowing additional user flexibility. This should be done using bipolar and referential reconstruction techniques. Playback systems should be able to display channel (montage) designations, gain or filter settings where appropriate, technologist comments, and event markers, along with the raw or transformed EEG data. A time stamp on each screen or page of EEG data is essential.

This statement is provided as an educational service of the ACNS. It is based on an assessment of current scientific and clinical information. It is not intended to include all possible proper methods of care for a particular problem or

all legitimate criteria for choosing to use a specific procedure, neither is it intended to exclude any reasonable alternative methodologies. The ACNS recognizes that specific patient care decisions are the prerogative of the patient and the physician caring for the patient, based on all of the circumstances involved. The clinical context section is made available to place the evidence-based guidelines into perspective with current practice habits and challenges. Formal practice recommendations are not intended to replace clinical judgment.

GUIDELINE

American Clinical Neurophysiology Society Guideline 5: Minimum Technical Standards for Pediatric Electroencephalography

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Summary: This revision to the EEG Guidelines is an update incorporating the current electroencephalography technology and practice. It was previously published as Guideline 2. Similar to the prior guideline, it delineates the aspects of Guideline 1 that should be modified for neonates and young children. Recording conditions for photic stimulation and hyperventilation are revised to enhance the provocation of epileptiform discharges. Revisions recognize the difficulties involved in performing an EEG under sedation in young children. Recommended neonatal EEG montages are displayed for the reduced set of electrodes only since the montages in Guideline 3 should be used for a 21-electrode 10-20 system array. Neonatal documentation is updated to use current American Academy of Pediatrics term "postmenstrual age" rather than "conceptional age." Finally, because therapeutic hypothermia alters the prognostic value of neonatal EEG, the necessity of documenting the patient's temperature at the time of recording is emphasized.

Key Words: Electroencephalography, EEG, Guideline, Technical, Neonate, Children, Pediatric, Hyperventilation, Photic Stimulation, Montage, Electrode, Filter, Postmenstrual Age, Conceptional Age, Therapeutic Hypothermia.

(J Clin Neurophysiol 2016;33: 320–323)

These Guidelines for clinical EEG recording in children should be considered in conjunction with the more general ACNS Guideline 1: *Minimum Technical Requirements for Performing Clinical Electroencephalography* (MTR), which covers primarily EEG recording in adults.

The basic principles of clinical EEG outlined in Guideline 1 also apply to the very young and are reaffirmed here. Special considerations pertinent to pediatric recordings are discussed below, with emphasis on the EEG in neonates, infants, and young children. EEG recording in older children and adolescents differs little from recording the EEGs of adults. Because EEG recording in the newborn presents a number of special problems; this Guideline is divided into two parts, setting forth recommendations for children and for neonates separately. [Notation in brackets in this Guideline refers specifically to sections of Guideline 1 which must be modified for pediatric recordings. For situations not covered here, the recommendations of Guideline 1 remain appropriate and should be consulted.]

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1. CHILDREN

1.1 [MTR 2.1]

Because children, especially young children, have a tendency to move a good deal during EEG recordings, electrode application should be performed with great care. Electrodes may be applied with paste or collodion, according to the preference of the laboratory, but their positions and impedances should be monitored carefully throughout the study. Needle electrodes should not be used.

1.2 [MTR 2.3]

All 21 electrodes of the International 10-20 system[1] should be used for most purposes. The standard montages used for adults should be used for children.

1.3 [MTR 2.4, 3.2]

Recommendations of MTR 2.4 and 3.2 should be followed. Particularly active children may require more frequent review of electrode recording quality during the recording.

1.4 [MTR 3.1]

Before recording the EEGs of young inpatients, especially those in so precarious a condition that the recordings must be

done at the bedside, the technologist should consult with the nursing staff concerning the patient's condition and about any necessary limitations on recording procedures.

1.5 [MTR 3.3]

The voltage of EEG activity in many young children is higher than that of older children and adults, and appropriate reduction of sensitivity (to 10 μV/mm, or even 15 μV/mm) could be used as needed. At least a portion of the record should be run at a sensitivity (such as 7 μV/mm) adequate to display low-voltage fast activity. Otherwise, for patients beyond infancy, the same instrument control settings can be used as for adults in the same laboratory.

1.6 [MTR 3.8]

It is advised to perform hyperventilation at the beginning and photic stimulation at the end of the recording to maximize spontaneous sleep.[2] If hyperventilation fails to elicit diagnostic findings in patients with suspected absence or other primary generalized seizures, a second trial of hyperventilation (done at least 10 minutes after the first trial) may have a higher yield.[3] Photic stimulation over the frequency range of at least 1 to 30 flashes per second should be used during wakefulness in appropriate patients.[4]

1.7 [MTR 3.8]

Whenever possible, recordings should include periods when the eyes are open and when they are closed. In infants over 3 months of age, passive eye closure (by placing the technologist's hand over the patient's eyes) is often successful in producing the dominant posterior rhythm, as is playing a game such as "peek-a-boo."

1.8 [MTR 3.9]

Sleep recordings should be obtained whenever possible, but not to the exclusion of the awake record. Recording the patient's EEG during drowsiness, initiation of sleep, and arousal is important, and this is best obtained with continuous EEG acquisition rather than pausing the recording in between states. Natural sleep is preferred, but sleep deprivation or melatonin may be helpful.[5] Discretion is required in choosing candidates for sleep deprivation as it may exacerbate problematic behavior in developmentally challenged patients. Use of sedation is the decision of the individual institution and physicians. The benefits of a sedated sleep recording must be weighed against the potential risks of sedation and/or its effect on the EEG.

1.9 [MTR 3.10]

The patient's clinical state (waking vs. drowsy vs. sleep) should be indicated clearly at the beginning of the recording and with each montage change. Continuous observation by the technologist, with frequent notation on the recording, is particularly important when recording young patients. This is especially true in situations during which the typical events or behaviors concerning for seizures are displayed by the patient. Whenever available, linking video to the EEG to capture these events may be helpful.

In stuporous or comatose patients and in those showing invariant EEG patterns of any kind, visual, auditory, and somatosensory stimuli should be applied systematically during the recording—but only toward the end of the recording period, lest normal sleep cycles be disrupted, or unexpected arousal-related artifact render the tracing unreadable. The stimuli and the patient's clinical responses or failure to respond should be noted on the recording as near as possible to their point of occurrence.

2. NEONATES AND YOUNG INFANTS (UP TO 4–8 WEEKS POSTTERM)

2.1 [MTR 1.1]

Recordings with at least 12 cerebral channels should be used, in addition to two, and often more, channels devoted to recording non-EEG "polygraphic" variables, such as electrocardiogram and respiration. Sixteen or more channels facilitate the necessary flexibility.

Because EEG patterns seen in the neonate are not as clearly related to stages of the wake–sleep cycle as are those of adults and older children, it is usually necessary to record polygraphic (non-EEG) variables along with the EEG to assess accurately the baby's state during the recording. Polygraphic recording is also helpful in identifying physiologic artifacts. For example, apparent monomorphic delta activity often turns out to be respiration artifact, as babies may have respiratory rates of up to 100/min. Moreover, variables other than the EEG may be directly pertinent to the patient's problems, for example, in children with apneic episodes, breathing and heart rate changes are often very important.

The parameters most frequently monitored along with EEG in infants are heart rate, respirations, and eye movements. Recording muscle activity by submental electromyography or movement transducer can also be very helpful.

Electrocardiogram should be recorded routinely and is particularly necessary when there are cardiac or respiratory problems, or when rhythmic artifacts occur.

Respirogram can be recorded by any of the following means: (1) abdominal and/or thoracic strain gauges, (2) changes in impedance between thoracic electrodes (impedance pneumogram), or (3) airway thermistors/thermocouples. In infants with respiratory problems, it is necessary to devote three or four channels to respiration to monitor both abdominal and thoracic movements, as well as airflow in the upper airway. In infants without respiratory problems, one channel of abdominal or thoracic respirogram may be sufficient.

Eye movements can be recorded by placing one electrode 0.5 cm above and slightly lateral to the outer canthus of one eye and another electrode 0.5 cm below and slightly lateral to the outer canthus of the other eye. They can be designated E1 and E2. Both lateral and vertical eye movements can be detected by linking (i.e., referring) the eye movement electrodes to auricular electrodes: E1 to A1 and E2 to A1 (or E1-A2, E2-A2).

2.2 [MTR 2.1]

Electrodes may be applied with either collodion or paste. For neonates, the fumes of acetone and ether may not be acceptable, and disk electrodes with electrolyte paste are preferable. Needle electrodes should never be used.

2.3 [MTR 2.3]

It is a matter of individual preference whether a reduced electrode array is acceptable for neonates. Some electroencephalographers prefer the full 21 electrodes of the International 10-20 system; others prefer a reduced array. It is generally agreed that a reduced array is acceptable in premature infants with small heads or where (as in neonatal intensive care units) time considerations or other circumstances may not allow application of the full electrode array. If 20 channels are available, it is possible to use standard adult 16-channel montages plus polygraphic variables.

If a reduced electrode array is used, the following electrodes (10-10 system nomenclature, with 10-20 system nomenclature in parentheses) are suggested as a minimum: Fp1, Fp2, C3, Cz, C4, T7 (T3), T8 (T4), O1, O2, Al, and A2. If a baby's earlobes are too small, mastoid leads may be substituted for A1 and A2 and can be designated Ml and M2. Acceptable alternative frontal placements in the reduced array are AF3 and AF4 instead of Fp1 and Fp2 (10-10 system nomenclature; see Guideline 2); AF3 is halfway between the Fp1 and F3 positions and AF4 halfway between the Fp2 and F4 positions.

Determining electrode sites by measurement is just as important in infants and children as in adults. Deviation from this principle is permissible only in circumstances in which it is impossible or clinically undesirable to manipulate the child's head to make the measurements. If an electrode placement must be modified because of intravenous lines, pressure bolts, scalp hematomas, and others, the homologous contralateral electrode placement should be modified similarly. If approximate rather than precise lead placement is done, the technologist should note this on the recording.

2.4 [MTR 2.4]

Electrode impedances of less than 10 kOhms are allowed to avoid excessive manipulation or excessive abrasion of tender skin. It is still important that marked differences in impedances among electrodes be avoided. Further details are in the [MTR 2.1] section.

2.5 [Guideline 3]

If a 21-electrode 10-20 system array is used, Guideline 3 recommendations should be followed as long as Cz is included. If a reduced array is used, a single montage that includes both longitudinal and transverse montages is recommended below (10-10 system nomenclature, with 10-20 system nomenclature in parentheses) (Table 1).

Note that channels 9 to 12 are a transverse bipolar chain with standard interelectrode distances rather than the double distances in channels 1 to 8. AF3 and AF4 (per 10-10 system nomenclature; see Guideline 2) may be substituted for Fp1 and Fp2, and M1 and M2 may be substituted for A1 and A2. If AF3 and AF4 are used, the reduced interelectrode distance must be taken into account when interpreting voltages in a bipolar montage.

TABLE 1. Neonatal Montage Examples

Channel	Montage A	Montage B	Montage C
1	Fpl-T7 (T3)	Fp1-C3	Fpl-T7 (T3)
2	T7 (T3)-O1	C3-O1	T7 (T3)-O1
3	Fp2-T8 (T4)	Fpl-T7 (T3)	Fp1-C3
4	T8 (T4)-O2	T7 (T3)-O1	C3-O1
5	Fp1-C3	Fp2-C4	Fp2-T8 (T4)
6	C3-O1	C4-O2	T8 (T4)-O2
7	Fp2-C4	Fp2-T8 (T4)	Fp2-C4
8	C4-O2	T8 (T4)-O2	C4-O2
9	T7 (T3)-C3	T7 (T3)-C3	T7 (T3)-C3
10	C3-Cz	C3-Cz	C3-Cz
11	Cz-C4	Cz-C4	Cz-C4
12	C4-T8 (T4)	C4-T8 (T4)	C4-T8 (T4)
13	ECG	ECG	ECG
14	Respiration	Respiration	Respiration
15	E1-A1 or A2	E1-A1 or A2	E1-A1 or A2
16	E2-A1 or A2	E2-A1 or A2	E2-A1 or A2
17	EMG	EMG	EMG

10-10 system nomenclature, with 10-20 system nomenclature in parentheses. ECG, electrocardiogram; EMG, electromyography.

The montages above are not the only permissible ones (for additional neonatal montages, see Ref. 6). Rather, they should be considered standard montages, and at least one of them should be used for at least a portion of a neonate's EEG recording in all laboratories, to provide some standardization among laboratories. Cz is always included because positive "rolandic" sharp waves (a common abnormal finding) and some seizures may only be detected at Cz in this population. Electrodes Fz, Cz and Pz are also used to visualize positive "rolandic" sharp waves.[7] Various other montages can be devised for special purposes, such as a montage combining referential and bipolar derivations.

The use of a single montage throughout the recording of a neonate may be, and often is, sufficient and is preferred in many laboratories. Nevertheless, a single montage is not always adequate. Even in laboratories preferring single montages, additional montages should be used when the need arises, for example, to delineate focal abnormalities better.

For recording polygraphic variables, the following derivations are recommended: (1) for electrocardiogram, lead 1 (right arm-left arm) is preferred; (2) for respiration, chest wall or abdomen movement (strain gauge or impedance pneumogram); (3) for eye movements (electrooculogram): E1-A1 and E2-A1 or E1-A2 and E2-A2; (4) for submental electromyography: two electrodes under the chin, each 1 to 2 cm on either side of the midline.

2.6 [MTR 3.1]

Before recording the EEGs of young inpatients, especially those in so precarious condition that the recordings must be done at the bedside, the technologist should consult with the nursing staff concerning the patient's condition and about any necessary limitations on recording procedures.

The baby's gestational age at birth, chronologic age, and postmenstrual age on the day of recording, stated in weeks, are absolutely essential to interpretation and must be included in the information available to the electroencephalographer (Postmenstrual age is gestational age plus chronological age.[8] Gestational age is the time elapsed between the first day of the last menstrual period and the day of delivery. Chronological age is the time elapsed since birth. Neonatal studies (past and present) sometimes use the term conceptional age when postmenstrual age is being measured. Some studies do not define the term conceptional age. This is an important distinction since conceptional age is the time elapsed between the day of conception and day of delivery, and therefore an infant with conceptional age of 24 weeks would have a gestational age of 26 weeks. To avoid confusing terminology, the American Academy of Pediatrics recommends using postmenstrual age and never using conceptional age.). All other available relevant clinical information (including blood gas results, serum electrolyte values, and current medications) should be noted for the electroencephalographer. If hypothermia is present, therapeutic or otherwise, it should be documented along with the patient's body temperature.

2.7 [MTR 3.3, 3.4]

In young infants' EEGs, the most appropriate sensitivity is usually 7 μV/mm, but adjustments up or down should be appropriately used to facilitate EEG interpretation. At least a portion of the recording should be run at a sensitivity adequate to display low-voltage fast activity. The low-frequency filter setting should be between 0.3 and 0.6 Hz (−3 dB) (time constants of 0.27–0.53 second), not the commonly used 1 Hz (0.16 second).

For electrooculogram, a sensitivity of 7 μV/mm and the same time constant as for the concomitantly recorded EEG derivations are recommended. For respirogram, amplification should be adjusted to yield a clearly visible vertical deflection. A low-frequency filter setting of 0.3 to 0.6 Hz, but not direct current, should be used. For the submental electromyography recording, a sensitivity of 3 μV/mm, a low-frequency filter setting of about 5 Hz (time constant of about 0.03 second), and a high-frequency filter setting of 70 Hz should be used.

2.8 [MTR 3.7, 3.8, 3.9]

If possible, it is advantageous to schedule the EEG at feeding time and arrange to feed the child after the electrodes have been applied but before beginning the recording, as babies tend to sleep after feeding.

Extra recording time should be allotted for neonatal EEGs. Time is commonly lost because of a greater number of movement and other physiologic artifacts during wakefulness, and extra time is usually needed to obtain a recording sufficient to permit the evaluation of stages of the wake–sleep cycle and other states.

Except when the EEG is grossly abnormal, 20- or 30-minute recordings are usually insufficient. In neonates with invariant patterns, it may be necessary to obtain at least 60 minutes of recording to demonstrate that the tracings are not likely to change. When there is EEG variability, adequate sampling of both major sleep states is important. The initial sleep state in the neonate is usually active sleep, which may last a very short time or continue for many minutes. An adequate sleep tracing must include a full epoch of quiet sleep. It is never necessary or desirable to use sedation to obtain a sleep recording in a neonate.

Repetitive photic stimulation is rarely, if ever, clinically useful in neonates and is not recommended.

2.9 [MTR 3.10]

The child's condition, including head and eyelid position, should be clearly indicated at the beginning of every montage. Continuous observations by the technologist, with frequent notation on the recording, are particularly important when recording from neonates.

DISCLAIMER

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GUIDELINE

American Clinical Neurophysiology Society Guideline 6: Minimum Technical Standards for EEG Recording in Suspected Cerebral Death

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Summary: This revision to the EEG Guidelines is an update incorporating current EEG technology and practice. The role of the EEG in making the determination of brain death is discussed as are suggested technical criteria for making the diagnosis of electrocerebral inactivity.

Key Words: EEG equipment, EEG electrode, EEG montage, EEG brain death, EEG report, Adult, Pediatric, Neonatal.

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This guideline emphasizes the basic principles and other important aspects of recording the EEG for the purposes of determining brain death. It serves to update what has been learned since the first iteration of minimum technical standards for the determination of brain death.[1–6] Clinical scenarios may vary by policies required by individual states or hospitals, so these guidelines for minimal standards must be taken in the context of individual resource availability. Consequently, this document should be considered as an expression of the optimal means of recording and not as an absolute requirement. In particular, because of the complexities involved in evaluating the preterm infant, these guidelines do not refer to those patients.

Many hospitals have intensive care units and perform EEG studies in the setting of clinically suspected cerebral death to confirm irreversible loss of all brain function.[7] For this reason, there is continued need for guidance in performing these important tests.

The first (1970) edition of *Minimum Technical Requirements for EEG Recording in Suspected Cerebral Death* reflected the state of the art and techniques of the late 1960s. Substantially improved EEG technology is now available, and many laboratories have had decades of experience in this area. Equally important, there is now a much larger complement of qualified EEG technologists.

An initial survey in the late 1960s by the American EEG Society's ad hoc Committee on EEG Criteria for the Determination of Cerebral Death revealed that, of 2,650 cases of coma with presumably "isoelectric" EEGs, only three cases with recordings satisfying the committee's criteria showed any subsequent recovery of cerebral function. These three patients had suffered from massive overdoses of central nervous system depressants. Many of the reported "isoelectric" records in adults were, on review, either low-voltage records or obtained with techniques inadequate to show low-voltage activity such that they gave the false appearance of being "flat."

Nonphysiologic terms such as "electrocerebral silence, isoelectric," "linear," and "flat" were replaced in the 1970s with the term "electrocerebral inactivity" (ECI) that seems in the Glossary of the International Federation of Clinical Neurophysiology (IFCN).[3] A recent study found that in 96.5% of patients, the EEG corroborated the clinical diagnosis of brain death, but in 3.5% of patients it did not[8]—particularly in patients with brainstem injury. In these patients, the EEG demonstrated electrical activity in patients who had a diagnosis of brain death on clinical grounds. A study in children[9] yielded different results: only 89% of patients with brain death had an EEG demonstrating ECI. There was a similar finding in neonates and children with radionuclide brain scans; when a single EEG was performed with a radionuclide brain scan, up to 17% of children without apparent flow on the scan still had cerebral activity on the EEG.[9]

DEFINITION

Electrocerebral inactivity is defined as the absence of nonartifactual electrical activity over 2 μV (peak to peak) when recording from scalp electrode pairs 10 or more cm apart when the recording is performed in compliance with the standards outlined below.

The guidelines for EEG recordings in cases of suspected cerebral death have eleven components, each set forth with explanatory comments. The basic principles of EEG recording

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still apply, and, unless modifications are noted below, Guideline 1 recommendations should be followed.

1. A Complete Complement of Scalp Electrodes Should Be Used

Electrodes must be placed over all major brain areas to be certain that the absence of EEG activity is not just a regional phenomenon. The use of single-channel or dual-channel recording devices such as those used for EEG monitoring of anesthetic levels is therefore unacceptable for the purpose of determining ECI. Especially because the EEGs of patients with suspected ECI may demonstrate abnormalities other than ECI, it is essential to use complete, rather than restricted, electrode coverage, as defined in Guideline 1: *Minimum Technical Requirements for Performing Clinical Electroencephalography*, Section 2.3. This should include midline placements (Fz, Cz, Pz) because these electrodes are useful for the detection of residual low-voltage physiologic activity and are relatively free from artifact. At times, recording with a full set of conventional 10-20 (or 10-10) scalp locations may not be feasible, for example because of head trauma or recent surgery. In this case, electrode positions may be moved as necessary, as long as careful documentation is made and the minimal interelectrode distances described below are attained. In this case, one option is to displace the same electrodes on the contralateral side by an equivalent distance to allow better comparisons between the two sides. The initial study should not use less than the routine coverage standard for the particular clinical laboratory.

The location of all electrodes placed should be well documented.

All recording devices require an isolated ground and a reference electrode to be connected to the patient. The device manual should be consulted before recording.

2. Interelectrode Impedances Should Be Less Than 10,000 Ohms but More Than 100 Ohms

2.1 Unmatched electrode impedances may distort the EEG. When one electrode has relatively high impedance compared with the second electrode of the pair, the amplifier becomes unbalanced and is prone to amplify extraneous signals unduly. This may result in 60-Hz interference or other artifacts. Situations characterized by low-voltage electrocerebral activity demand especially scrupulous electrode application. In addition, electrodes with high impedance even if matched may be associated with increased noise that could obscure a low-amplitude signal.

2.2 There is a marked drop-off of potentials with impedances below 100 Ohms and, of course, no potential at 0 Ohms. This could be one possible reason for a false ECI record. A test of interelectrode impedances, to assure that they are of adequate magnitude, should be performed during the recording. It is essential that excess electrode paste does not spread from one electrode to another, creating a shunt or short circuit, which would also attenuate the signal.

Stable, low-impedance electrodes are absolutely essential for all bedside (i.e., away from the laboratory) studies.

2.3 The use of needle electrodes and "electrode caps" should be avoided.

3. The Integrity of the Entire Recording System Should Be Tested

If, after recording with one montage at increased amplification, an EEG suggesting ECI is found, the integrity of the system should be tested by touching each electrode of the montage gently with a pencil point or cotton swab to create an artifact potential on the record. This test verifies that the electrode board is connected to the recording device. Records made with the electrode board inadvertently not connected can sometimes resemble low-amplitude EEG activity. The test also proves that the montage settings match the electrode placements.

4. Montages for ECI Interpretation Should Include Electrode Pairs At Least 10 Centimeters Apart

In the International 10-20 System, the average adult interelectrode distances are between 6 and 6.5 cm. A recording taken with average interelectrode distances at ordinary sensitivity might suggest ECI, but if it were recorded using longer interelectrode distances, cerebral potentials might be seen in the tracing. Hence, with longitudinal or transverse bipolar montages, several double distance electrode linkages are recommended (e.g., Fpl-C3, F3-P3, C3-O1, etc.). The use of the 10-10 System is also acceptable, using electrodes from similar locations on the scalp.

Ear reference recording is almost invariably too contaminated by electrocardiogram to be useful, but a montage including a Cz reference may be satisfactory as long as an interelectrode distance of 10 cm or more is maintained. In one study,[1] the best montage included: Fp2-C4, C4-O2, Fpl-C3, C3-Ol, T4-Cz (T8-Cz in the 10-10 system), Cz-T3 (Cz-T7 in the 10-10 system), with one-channel electrocardiogram and one-channel noncephalic recording (e.g., on the hand). Occipital leads, however, are more difficult to attach in immobilized patients and are particularly susceptible to movement artifact induced by artificial respirators. A montage that includes F7-T5 (F7-P7 in the 10/10 system), F8-T6 (F8-P8 in the 10-10 system), F3-P3, F4-P4, and Fz-Pz may therefore yield a better record.

None of the foregoing should imply that the usual preselected laboratory montages could not be used in addition.

5. Sensitivity Must Be Increased to a Maximum of 2 μV/mm for At Least 30 Minutes of the Recording

5.1 This is undoubtedly the most important and the most often overlooked specification. At a sensitivity of 7 μV/mm, a signal of 2 μV cannot be seen because it would be less than 0.3 mm in magnitude; on most computer monitors, a single pixel is about 0.25 mm. Recording at a sensitivity of 1.5 or 1 μV/mm provides an additional 50% to 100% increase in sensitivity and will allow a more confident assessment of the presence, or the absence, of a 2-μV signal. It is important to include appropriate calibrations for the specific recording device used.

5.2 Adequate and appropriate calibration procedures are essential. It is good practice to calibrate with a signal near the

size or value of the EEG signal that has been recorded. Thus, for ECI, a calibration signal of 2 or 5 μV is appropriate. A 50-μV calibration signal at a sensitivity of 2 or 1 μV/mm is useless because the monitor traces may overlap. The inherent noise level of the recording device should also be measured as in section 7.5.

5.3 It is important to understand the calibration function on the recording device being used and particularly whether it tests the amplifiers or only the display. Nevertheless, adequate calibration does not exclude the possibility of shunting or an open circuit at the electrodes, electrode board (jackbox), cable, or input of the recording device.

5.3 Self-limited periods of ECI of up to 20 minutes may occur in low-voltage records,[10] so each recording should be at least 30 minutes long to be certain that intermittent low-voltage cerebral activity is not missed.

6. Filter Settings Should Be Appropriate

To avoid attenuation of low-voltage fast or slow activity, high-frequency (low pass) filters should not be set below 30 Hz, and low-frequency (high pass) filters should not be set above 1 Hz.

Short time constants (high values of the low filter) attenuate slow potentials. In the situation approaching ECI, there may be potentials in the theta and delta ranges, so every effort should be made to avoid attenuation of this low-frequency activity. Nevertheless, it has been demonstrated that a low-frequency setting of 1 Hz is adequate for the determination of ECI.[1,10] The 60-Hz notch filter can be used with care, and only after appropriate troubleshooting is performed. If the 60-Hz filter is used, segments of EEG should also be recorded without this filter for comparison.

7. Additional Monitoring Techniques Should Be Used When Necessary to Clarify the Record

The EEG record is a composite of true brain waves, other physiologic signals, and artifacts (either internal or external to the recording device, and of mechanical, electromagnetic, and/or electrostatic origin). When the sensitivity is increased, such artifacts are accentuated and therefore, must be identified to accurately assess whether true EEG activity is present. It should be emphasized that the best insurance against many artifacts is a stable, low-impedance electrode system. A wide range of artifacts is present in the patients who sustain severe brain insults requiring special care.[11] These are illustrated in the *Atlas of Electroencephalography in Coma and Cerebral Death*[1] in *Current Practice of Clinical Electroencephalography*[12] and the *Atlas of EEG in Critical Care*.[13]

7.1 Because one rarely sees an ECI record without varying amounts of electrocardiogram artifact, an electrocardiogram monitor is essential.

7.2 If respiration artifact cannot be eliminated, the artifact must be documented by specific technologist notation on the record or be monitored by a transducer. Disconnecting the respirator (briefly) will allow definitive identification of the artifact, if clinically appropriate. Review of accompanying video can also be of assistance.

7.3 Frequently, an additional monitor is needed for other artifacts emanating from the patient or the local environment. The most convenient for this purpose is a pair of electrodes on the dorsum of the hand separated by about 6 to 7 cm. The technologist should be aware of frequent sources of electrical artifact, including electric beds, IV drips, blood warmers, or other electrical devices. The technologist should place additional monitors when they help to clarify the source of artifact. For example, intermittent movements noted in a limb should prompt placement of a movement monitor to help differentiate movement-induced artifact from electrocerebral activity.

7.4 It is clear that some electromyogram contamination can persist in patients with ECI recordings. If electromyogram potentials are of such amplitude as to obscure the tracing, it may be necessary to reduce or eliminate them by using a short-term neuromuscular blocking agent. Because this may interfere with the neurologic examination and cause other problems, neuromuscular blockade should be performed under the direction of an experienced physician familiar using medications in critically ill patients.

7.5 Machine noise, thermal noise, and electrical interference entering the recording system from the jack box to the amplifiers may be checked conveniently by placing a 10,000-Ohm resistor between input terminal 1 (G1) and input terminal 2 (G2) of one channel, as long as either G1 or G2 is shorted to the reference electrode.

7.6 Even with good technique, however, an EEG recorded at the increased sensitivities required above can occasionally present diagnostic challenges to the interpreting electroencephalographer. An attempt must be made to determine what portion of the record results from noncerebral physiologic signals or nonphysiologic artifacts, including the ongoing noise level of the complete system in that particular intensive care unit, as indicated, for example, by a recording from the hand. An estimate must then be made of whether or not the remaining activity exceeds 2 μV in amplitude. When this cannot be performed with confidence, the EEG report must indicate the uncertainty, and the record cannot be classified as demonstrating ECI (see Section 10).

7.7 Continuous video recording is strongly encouraged to help identify any artifacts in the recording. Furthermore, recognizing the source of the artifact to "troubleshoot" and eliminate or camouflage it from the record requires a coordinated team, including trained technologists, nurses, personnel experienced in informatics, and neurophysiologists, to ensure optimal interpretation.

8. There Should Be No EEG Reactivity to Intense Somatosensory, Auditory, or Visual Stimuli

Lack of reactivity in critically ill patients is associated with an increase in mortality.[14] In this collaborative study, there was no instance of stimulus-related activity in EEG recordings of patients with ECI.[1,5,6] Any apparent EEG activity resulting from the above stimuli or any others (airway suctioning and other nursing procedures can be potent stimuli) must be carefully distinguished from noncerebral physiologic signals and from nonphysiologic artifacts. For example, an electroretinogram can persist in response to photic stimulation

when there is ECI. Stimulation may also be of help in documenting the degree of reactivity in records not demonstrating ECI.

9. Recordings Should Be Performed Only by a Qualified Technologist

Great skill is essential in recording cases of suspected ECI. Frequently, recordings are made under difficult circumstances and include many possible sources of artifact. Elimination of most artifact, and identification of all others, can be accomplished only by a qualified technologist.

Qualifications for a competent EEG technologist for ECI recordings include the requirement of supervised instruction in the techniques of recording in intensive care unit settings, as well as previous successful performance of ECI recordings under direct supervision. In addition, Registry in EEG Technology (R. EEG T.) is encouraged for technologists performing such studies. The technologist should work under the direction of a qualified electroencephalographer. The American Academy of Neurology and the American Clinical Neurophysiology Society, in conjunction with the American Board of Clinical Neurophysiology, have established guidelines for physician standards of reporting and interpretation.

10. A Repeat EEG Should Be Performed When ECI Is in Doubt

In the Collaborative Study of Cerebral Death,[1,5,6] there were no patients who survived for more than a short period after an EEG showed ECI—provided that overdose of depressant drugs was excluded. This finding confirmed the results of the earlier survey summarized in the Introduction. It is evident, therefore, that a single EEG showing ECI is a highly reliable procedure for the determination of cortical death. While that is likely true for term neonates and children, an EEG cannot substitute for a neurologic examination in a brain death evaluation. (For other guidelines to assist physicians in the determination of brain death, see the References.)

In the event that technical or other difficulties lead to an inconclusive EEG evaluation of ECI, the entire procedure should be repeated after an interval to resolve any uncertainty. This may be as short as 6 hours in adult patients, but in neonates and children the interval should be at least 24 hours. Consideration could be given to other confirmatory tests if, in the opinion of the treating physicians, technical limitations are unlikely to be overcome in subsequent recordings.

11. Recording of Physiologic Variables and Medications

EEG is subject to many errors in interpretation, some involving nonphysiologic variables.[15] Nevertheless, physiologic variables and the effects of medication are equally important because low core temperature and iatrogenic hypothermia can cause reversible cerebral inactivity.[16] In addition, the blood pressure and oxygen saturation should be recorded, because both hypotension and hypoxemia can cause loss of cerebral activity. Finally, it is important to record all medications the patient is taking, as well as the last time that the patient received any sedating medications such as barbiturates, benzodiazepines, propofol, or narcotics. If the patient has had a toxicology screen, the technologist should also document the results.

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GUIDELINE

American Clinical Neurophysiology Society Guideline 7: Guidelines for EEG Reporting

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Summary: This EEG Guideline incorporates the practice of structuring a report of results obtained during routine adult electroencephalography. It is intended to reflect one of the current practices in reporting an EEG and serves as a revision of the previous guideline entitled "Writing an EEG Report." The goal of this guideline is not only to convey clinically relevant information, but also to improve interrater reliability for clinical and research use by standardizing the format of EEG reports. With this in mind, there is expanded documentation of the patient history to include more relevant clinical information that can affect the EEG recording and interpretation. Recommendations for the technical conditions of the recording are also enhanced to include post hoc review parameters and type of EEG recording. Sleep feature documentation is also expanded upon. More descriptive terms are included for background features and interictal discharges that are concordant with efforts to standardize terminology. In the clinical correlation section, examples of common clinical scenarios are now provided that encourages uniformity in reporting. Including digital samples of abnormal waveforms is now readily available with current EEG recording systems and may be beneficial in augmenting reports when controversial waveforms or important features are encountered.

Key Words: EEG, Reporting, Routine, Adult, Pediatric, Guideline.

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The purpose of this guideline is to provide a standardized format for reporting the results of adult routine scalp electroencephalography (rsEEG). The moderate interobserver reliability of EEG interpretation may be partly explained by the different reporting styles utilized,[1] and there is significant variability in the observation of guidelines for EEG reporting.[2] Computer-based remote access technology has become more sophisticated, and video is now "routine" during rsEEG, prompting the need to revise and update the earlier ACNS guideline on "Writing an EEG Report".[3] To assist in producing useful information for clinical and research purposes, standardized terminology and following an orderly approach to EEG reporting is recommended.[4]

This guideline is designed to outline the conditions and parameters of EEG recording, including a description of the record obtained and the final impression that summarizes the EEG's visual analysis. Its framework is intended to be useful to a clinician providing general neurologic care (including in the primary care setting) who may not be an expert on the technical aspects of EEG or on the terminology in the rsEEG report.[5] Proper interpretation of the results reported depends on minimum technical standards for the performance of an EEG [see "*Minimum Technical Requirements for Performing Clinical EEG*" available at http://www.acns.org/practice/guidelines]. Also, it is clear that consistently higher interobserver agreement occurs when there is a forced choice paradigm using a limited set of EEG terms.[6] This guideline intends to provide a framework for the EEG report to address the features as normal or abnormal, with subsequent specification of their clinical importance. The significance should be evident to the clinician and the findings readily interpretable within the patient-specific context of the rsEEG recording.

When reporting specialized types of EEG (e.g., electrocerebral inactivity, or neonatal EEGs) or EEG recordings in special settings, or for prolonged durations (e.g., continuous EEG in critical illness or during video-EEG monitoring), there may be modification with special formats more applicable to those specific settings. In these situations, the description of technical details should be enhanced and more complete than is required for standard rsEEG reporting. Also, the guidelines described below are not intended to be the sole means of reporting for institutions where research indexing may apply. Guidelines have been developed by the American Clinical Neurophysiology Society (ACNS) to provide the appropriate means of recording in some special situations. Standardized reporting of clinical neurophysiologic procedures has been implemented successfully.[7] The current guideline on "EEG Reporting" complements the earlier "*Writing an EEG Report*" and supplements those on nonroutine recording situations and locations, available at http://www.acns.org/practice/guidelines.

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FORMAT FOR REPORTING

A standard format for rsEEG reporting should include five sections: History, Technical Description, EEG Description, Impression, and Clinical Correlation.

History

The history section is an aid to interpretation of the rsEEG and should be succinct, including the reason for obtaining the recording and any relevant clinical information, as well as identification of the patient and EEG recording.

Templates for reporting EEGs should supply information and demographics about the patient. Personal information should include patient identification, including the medical record number (or other unique patient identifier) and clinical/hospital EEG record number, in addition to the last name, first name, sex, and date of birth and age at the time of the recording. The purpose of the EEG should also be documented, e.g.,: (1) to evaluate patients with spells of altered consciousness, (2) to document and classify epileptiform discharges in patients with recurrent seizures and epilepsy, and (3) to evaluate patients for nonconvulsive seizures and for status epilepticus. This essential information should be entered by the person who prepares the recording for the final interpretation. Relevant clinical information should be available in the worksheet prepared by the technologist performing the EEG recording (Guideline 1: *Minimum Technical Requirements for Performing Clinical Electroencephalography*, section 3.1). This should include relevant medical history, neuroactive medications including sedatives and antiseizure drugs, neuroimaging results, note of any cranial operations, and whether previous EEGs have been performed.

Technical Description

The technical description should detail the conditions and parameters of the recording, including the date and location of acquisition and interpretation—to ensure that both are identified in case the rsEEG is interpreted days after the recording. Technical parameters should include the number of electrodes used and that the placement was in accordance with the 10 to 20 or 10 to 10 International System of Electrode Placement. Minimum standards for performing an EEG (e.g., head measurement) are required (see also, Guideline 1: *Minimum Technical Requirements for Performing Clinical EEG*). Additional electrodes (e.g., T1/T2, sphenoidal, or subtemporal electrodes), special electrodes (e.g., eye movement monitors), and modifications of the 10 to 20 and 10 to 10 System (e.g., "prime" electrodes used when there are skull defects or alteration) should be included. Special parameters (outside those recommended in Guideline 1, sections 3.3–3.6) used during post hoc review of the rsEEG should be included in this section. An example of the technical description follows: "This is a 21-channel digital EEG recording with time-locked video and single-channel electrocardiogram. Electrodes are placed according to the 10 to 20 (or 10–10) International System. Portions of this record are reviewed using bandpass filters of 2 to 35 Hz and sensitivity of 20 μV/mm." Reporting the total recording duration may also be helpful, especially if it deviates from the minimum technical requirements for performing clinical EEG (Guideline 1, section 3.7). This is particularly advisable when it is shorter or longer than recommended for routine scalp EEG recording.

The conditions of the recording should be elucidated. A statement regarding the use of premedication should include the drug and dose (e.g., "lorazepam 1 mg was administered before the recording"). Other conditions that can influence the EEG should also be documented, including sleep deprivation, potential dietary influences (e.g., fasting or NPO status), and modality used (rsEEG, ambulatory EEG etc.).

The patient's state of consciousness should be documented, including if the patient is awake, drowsy, asleep, or in a compromised level of consciousness such as coma or coma-like states. This information on the patient's state, i.e., the level of consciousness, helps guide the interpretation of the EEG and electroclinical correlation.

EEG Description

This section should include a description of the background electrocerebral activity, including all the essential characteristics of waveforms in the record, detailed as objectively as possible.

The EEG signals are complex, and extraction of clinically relevant features by visual analysis alone is subject to individual variability. Although automated software application enhances our ability to detect and quantify the power of specific bandwidths of EEG, human extraction of the clinically relevant features requires identification, integration of various bandwidths, and interpretation of the significant features in the context of the overall recording.

Description of the record should provide an objective means of analysis for review at a different time or by another interpreter. It should use technical terminology and metrics to detail the waveforms present for the duration of the recording. The aim is to provide a complete, objective, and orderly description of the state of the patient, the background activity, and the most salient features of the EEG to allow a conclusion of "normal" or "abnormal." It should also identify and describe normal variants in addition to abnormal findings. When an abnormality is identified, the degree of abnormality should be stated.

The rsEEG description should begin with a complete description of the background activity, including the posterior dominant rhythm, additional features of the background, and special features. The description of the best *posterior dominant rhythm* in units of frequency (Hertz (Hz), or cycles per second) and amplitude (microvolts per millimeter) should be reported with the patient in the most alert state. Records obscured by artifact, recordings in infants, and some normal records may not have a clearly defined posterior dominant frequency, and the report should reflect this. Response or reactivity to external stimuli should also be noted. Subsequent *nondominant background activity* should be identified by principal frequencies, amount of each present, degrees of symmetry, location/distribution, morphology, amplitude, and rhythmicity, using the same units as for the posterior dominant frequency. Description of nondominant background activity should include beta, theta, and delta activity. Terms such as "low," "medium," and "high" voltage may be used but should be quantified with numerical measures.

State changes in the patient should be documented. The level of alertness, the organization of the EEG background frequency and amplitude over time, and the spatial features of the recording should be noted. Sleep patterns and architecture should

be reported to reflect all sleep stages attained during the EEG recording. Abnormal patterns such as rapid sleep cycling, sleep-onset rapid eye movements, and asymmetry or attenuation in the normal sleep elements (e.g., spindles) should be noted.

Hyperventilation and intermittent photic stimulation are routine activating procedures used to trigger abnormalities during rsEEG. They should be performed and their effects noted. When omitted, the reason for their omission should be stated. If augmentation of slowing or any epileptiform abnormalities are encountered in the rsEEG during or after activating procedures, these responses should be detailed. Documentation of poor effort with hyperventilation is relevant to rsEEG interpretation. If additional methods are used to enhance EEG abnormalities, they should also be documented.

Any special characteristics present in the background, such as voltage attenuation or augmentation, suppression-burst activity, or electrocerebral inactivity should be detailed using the same terminology used to describe the background. Descriptions should note morphology (monomorphic, polymorphic, or irregular), rhythmicity, voltage, continuous versus intermittent features, laterality (e.g., left or right; bilateral, or diffuse), region of involvement (e.g., frontal, temporal, central, parietal, occipital), and frequency (e.g., theta, delta slowing). For epileptiform and nonepileptiform features with bilateral localization, amplitude symmetry (e.g., $>$ 50%) and synchrony (e.g., secondary bilateral synchrony vs. bilateral synchronous) should be included in the description, as well as the temporal pattern of their occurrence (e.g., bursts, prolonged runs, or sporadic).

Salient abnormal features should be noted following identification of the state and background activity. When interictal epileptiform discharges are present, one should document the location, morphology (e.g., spike, sharp, polyspike $\pm$ slow wave), pattern (e.g., single, run, random, rhythmic, periodic), and incidence (e.g., rare, intermittent, occasional, frequent, continuous). Further description of the frequency in Hertz should be included and the pattern of occurrence (e.g., single, couplet, bursts, and a train), as well as their duration. In addition, some abnormal findings may be influenced by external stimulation (e.g., stimulus-induced, rhythmic periodic ictal-like discharges). Quantifying paroxysmal abnormalities is often expressed in a subjective manner and is relative to individual reporting designs.[1,7]

Snapshots of a reported abnormality are encouraged to be included in the EEG report. This will help facilitate an understanding of what is being identified as an abnormality (Fig. 1). By providing a patient sample of the EEG abnormality, more universal validation will be enabled, beyond the report's text.

The presence of an electroclinical seizure or electrographic (i.e., without clinical manifestations) seizure should include description of the electrographic onset, field of propagation, and postictal period, defining the temporal and spatial characteristics and using terminology to define the location, distribution, morphology, amplitude, and rhythmicity, in addition to the duration and frequency of recurrence. When present, any clinical changes and the qualitative nature of the change should be documented, as described below under video recording.

Artifacts are present in virtually every rsEEG. They should be reported when they mimic cerebral activity, when they are unusual or excessive (e.g., eye movements or muscle activity), when they interfere with interpretation of the record ($>$50% of the tracing involving $>$50% of the electrodes), or when they provide valuable diagnostic information (e.g., myokymia, nystagmus, etc.).

A single-channel electrocardiogram should be included in every EEG. Reporting electrocardiogram findings in the EEG description will vary and depend on the interpreter's level of expertise. Other channels such as eye movement monitors (used by some laboratories routinely), channels monitoring respiration, movement, EMG, and noncephalic monitors should be reported and described when applicable and when their significance is questioned (Guideline 1: *Minimum Technical Requirements for Performing Clinical EEG*).

Video recording is a routine part of most proprietary systems for performing rsEEG. Including video descriptions in the report is important for providing additional information involving electroclinical episodes and seizures, and in assessing artifacts. The main features should include a description of the clinical event and, when possible, terminology used by the International League Against Epilepsy seizure classification system[8] reporting the duration, level of responsiveness/consciousness, and any intervention provided.

Impression

The impression (or interpretation) is a synthesis of the significance of the EEG findings. It is written primarily for the referring clinician and should, therefore, be as succinct as possible, and readily understandable to a clinician of any level of expertise or specialty. It should include an initial, clear summary statement as to whether it is a normal or an abnormal record. When the EEG is abnormal, the reasons why should be listed in a clear and concise line item format, in part to simplify the results for comparison among successive records. It is desirable to list the abnormalities by degrees of importance (examples: (1) a left focal temporal electrographic seizure; (2) left anterior temporal spike-and-waves; (3) left temporal delta slowing; and (4) mild slowing of the background activity).

The summary of the findings should be stated succinctly in layman's terms. When reporting several types of abnormalities, the list should be limited to the most salient findings and to the minimum number necessary to convey the significance of those findings (preferably no more than three or four). Often, the impression will be the only part of the report of major interest to the clinician, so the importance of this section is stressed. The impression should avoid confusing terminology and technical jargon, but "epileptiform discharges," including "spikes and sharp waves" are universally accepted terms.

Clinical Correlation

The clinical correlation is the ultimate translation of the EEG. It should integrate the reason for referral for the EEG and the findings to be used jointly to assist with patient management. The clinical correlation should clearly express the relevance of the findings to the clinician. Avoiding technical terminology is helpful to convey the message to the least experienced clinician

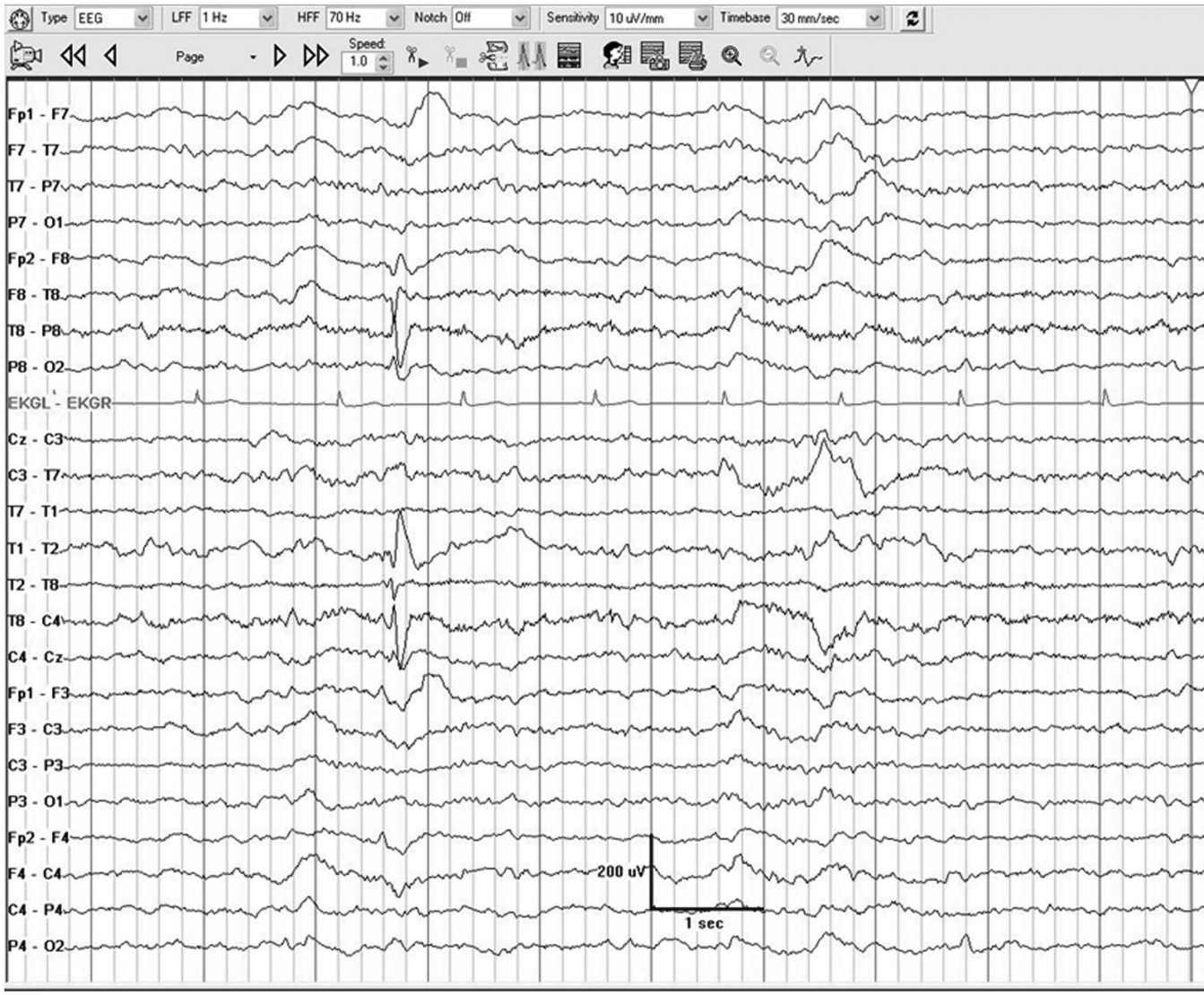

FIG. 1. A single right temporal spike-and-wave with a regional temporal field during drowsiness.

on the team caring for the patient. A good litmus test is that this section should be understandable to a general practitioner or nurse.[4]

Phrases such as "no focal or lateralizing abnormality," "no epileptiform abnormality," and "no electrographic seizures or evidence of status epilepticus were present" are helpful in the clinical correlation when the clinical request is explicit. Some common scenarios will be consistent from patient to patient. Although individual reporting styles vary and wording differs slightly, the following are examples of clinical correlations that may be used to express such concepts:

1. "A normal interictal EEG *does not* exclude nor support the diagnosis of epilepsy."
2. "Focal slowing suggests an underlying lesion involving the white matter of the ipsilateral hemisphere."
3. "Diffuse slowing of the background activity reflects a (include degree: mild, moderate, and severe) diffuse cortical dysfunction, which can be seen with toxic-metabolic or systemic causes, or neurodegenerative disorders, and also with cortical injury."
4. "The generalized spike-and-waves seen in this tracing imply a generalized mechanism in a patient with a clinical diagnosis of epilepsy but may also represent an inherited trait independent of clinical seizures."
5. "The left anterior temporal spikes suggest focal hypersynchrony in a patient with a clinical diagnosis of epilepsy and carry a heightened risk for focal-onset seizures of temporal lobe origin."
6. "The suppression-burst pattern following normothermic cardiac arrest (in the absence of anesthetic drugs) suggests a poor prognosis for neurologic outcome."

Although the clinical correlations in these cases may help standardize reporting, specific therapeutic suggestions such as "this pattern warrants antiseizure drugs" or "clinical correlation is strongly advised" should be avoided, recognizing the diagnostic limits of an rsEEG. Suggestions for further testing may be made within this section, e.g., suggesting a repeat EEG with sleep-deprivation, ambulatory EEG, video-EEG monitoring, referral to a sleep laboratory when sleep apnea is suspected, or further cardiologic evaluation when the electrocardiogram is abnormal. When previous EEGs are available, comparison of the current record to previous tracings should be included.

Note: Some electroencephalographers prefer to combine the Impression and Clinical Correlation, especially when they are simply stated and brief, e.g., "Normal routine EEG in wakefulness and in sleep." If a combined report is used, it should start with the neurophysiologic findings (usually the abnormalities), followed by comments about the clinical significance.

This standardized reporting format is intended to maximize clear communication among different reviewers of the same patient's rsEEG. It is hoped that this will facilitate interobserver reliability of EEG reporting for clinical care of patients and increase consistency for research studies.

DISCLAIMER

This statement is provided as an educational service of the American Clinical Neurophysiology Society (ACNS). It is based on an assessment of current scientific and clinical information. It is not intended to include all possible proper methods of care for a particular problem or all legitimate criteria for choosing to use a specific procedure, neither is it intended to exclude any reasonable alternative methodologies. The ACNS recognizes that specific patient care decisions are the prerogative of the patient and the physician caring for the patient, based on all of the circumstances involved. The clinical context section is made available to place the evidence-based guidelines into perspective with current practice habits and challenges. Formal practice recommendations are not intended to replace clinical judgment.

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