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### Correspondence to

#### The Korean Society of Clinical Neurophysiology

Daeil Building 1111, 12 Insadong-gil,  
Jongno-gu, Seoul 03163, Korea  
Tel: +82-2-2291-2290  
Fax: +82-2-737-6531  
E-mail: [kscn@kscn.or.kr](mailto:kscn@kscn.or.kr)

<http://www.e-acn.org>

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## Fundamental requirements for performing electroencephalography

Dae Lim Koo<sup>1</sup>, Won-Joo Kim<sup>2</sup>, Sang-Ahm Lee<sup>3</sup>, Jae Moon Kim<sup>4</sup>, Juhan Kim<sup>5</sup>, Soochul Park<sup>6</sup>;  
and on behalf of the Korean Society of Clinical Neurophysiology Education Committee

<sup>1</sup>Department of Neurology, Seoul National University Boramae Hospital, Seoul, Korea

<sup>2</sup>Department of Neurology, Gangnam Severance Hospital, Yonsei University College of Medicine, Seoul, Korea

<sup>3</sup>Department of Neurology, Asan Medical Center, University of Ulsan College of Medicine, Seoul, Korea

<sup>4</sup>Department of Neurology, Chungnam National University Hospital, Daejeon, Korea

<sup>5</sup>Department of Neurology, Hanyang University Seoul Hospital, Seoul, Korea

<sup>6</sup>Department of Neurology, Yonsei University College of Medicine, Seoul, Korea

The performance of electroencephalogram (EEG) recordings is affected by electrode type, electronic parameters such as filtering, amplification, signal conversion, data storage; and environmental conditions. However, no single method has been identified for optimal EEG recording quality in all situations. Therefore, we aimed to provide general principles for EEG electrode selection as well as electronic noise reduction, and to present comprehensive information regarding the acquisition of satisfactory EEG signals. The standards provided in this document may be regarded as Korean guidelines for the clinical recording of EEG data. The equipment, types and nomenclature of electrodes, and the details for EEG recording are discussed.

**Key words:** Electroencephalography; Electrode; Epilepsy

## INTRODUCTION

Electroencephalographic measurements are commonly used for both clinical and research purposes. In this report, we present an introduction to performing electroencephalogram (EEG) recording. Although there is no single method for obtaining optimal EEG results in all circumstances, the following standards can be considered references for standard recording of clinical EEG data.<sup>1</sup> The document is divided into three parts: in the first part, we discuss standards for EEG recording equipment, while the types and nomenclature of electrodes are discussed in the second part. The final part discusses the details of EEG recording.

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## FACILITIES FOR EEG RECORDING

1. To localize abnormalities using EEG, EEG activity should be simultaneously recorded from as many brain locations as possible, as the chance of errors increases during analysis when relatively few channels are used. In contrast, increasing the number of channels reduced the chance of errors. This is especially useful in the analysis of transient activity. A minimum of 16 channels of concurrent recording are required, although more channels can be added under various circumstances.
2. Alternating current (AC) connections should correspond with a standard specification, and all equipment should be accompanied by grounding equipment. Moreover, all equipment in the EEG room should be earthed to a common ground point.
3. Electrical shielding is not necessary for EEG rooms in standard clinical settings, and such an installation of shielding is not mandatory unless proven necessary.
4. Photic stimulation equipment with rhythmic high-intensity flash is mandatory.
5. Digital EEG has multiple advantages (greater sensitivity and reliability, possibility of modification after EEG recording, and convenience of EEG storage) compared to paper-based EEG recording.

## TYPES OF ELECTRODES

1. Electrodes used for recording should be free of noise, and there should be no drifting of electrodes. Signals in the range of 0.5–70 Hz should not be attenuated. Disk-shaped electrodes of silver, silver chloride, or gold held by colloid provide optimal results. Other types of electrodes materials and pastes (e.g., electrode cream, electrode gel) can be used efficiently in certain situations. To minimize noise, electrodes should always be sterilized and kept free from contamination, especially when recording EEG data from patients with infectious diseases (viral hepatitis, Creutzfeldt-Jakob disease, human immunodeficiency virus infection, etc.).<sup>2</sup>
2. Invasive electrodes such as needle electrodes are not recommended for routine EEG recording. If necessary, the invasive electrodes must be completely sterilized and dis-

carded after use. Technologists who use invasive electrodes should be aware of the advantages and disadvantages of their use. Wire or subdermal needle electrodes are useful for prolonged EEG recording in stuporous or comatose patients, in whom application of cup electrodes is not feasible. Needles must be placed in parallel, as improper arrangement may result in distortion or asymmetry of amplitudes.

3. Nomenclature and application of 21 electrodes is recommended by the International Federation of Clinical Neurophysiology (IFCN, 1983). The international 10-20 system, which is the only system officially recommended by the IFCN, may be clinically adequate for most patients and efficient with regard to time, effort, and cost. This is the most commonly applied system and should be used universally. The “modified 10-20 system” is not recommended, as the placement of electrodes by assumption without proper head measurement can result in undesirable and misleading results. The “10-10 system” follows the extended combinatorial system described in American Clinical Neurophysiology Society (ACNS) Guideline 2, though ACNS Guideline 5 should be used for neonates.<sup>3,4</sup> The names of some electrodes in the 10-10 system differ from those outlined in the 10-20 System. For example, the T3 and T4 electrodes of the 10–20 system are referred to as T7 and T8 in the 10–10 system, while T5 and T6 of the 10-20 system are referred to as P7 and P8 in 10–10 system. An adequate number of electrodes is essential for detection small areas of scalp EEG activity or for estimating more extensive EEG signals. The application of fewer electrodes is usually not recommended except in special circumstances. Additional electrodes can be placed on the top, bottom, left, and right of the standard electrodes. The ground electrode must be inserted into the appropriate jack of the input jack box.
4. Interelectrode impedance must be evaluated prior to routine EEG recording, as this value should not exceed 5 k $\Omega$  during routine scalp EEG recording. However, in digital EEG recording systems, impedances up to 10 k $\Omega$  are tolerable. Interelectrode impedance should be re-evaluated during recording if unwanted artifacts or signals are observed.<sup>5</sup>

## EEG RECORDING

Montages should be assigned according to ACNS Guideline 3.<sup>6</sup>

At least some montages should be uniform to enable communication and comparison among all EEG recording laboratories. Digital EEG systems are advantageous in that they allow for easy switching of montages at the time of interpretation. In such circumstances, the initial recording should be used as the reference montage. Additional electrodes (or a combination of electrodes) must be placed as a reference in digital systems, rather than utilizing electrodes already included in the 10-10 or 10-20 system. Additional electrodes attached between Cz and Pz are commonly used as reference electrodes.<sup>1</sup>

1. When performing EEG, information regarding the patient's name, age, date of the recording, identification number, and the name of technologist should be recorded, at minimum. Additional information such as test duration, date and time of last seizure, the patient's mental and behavioral status, medication (including sleeping pills and antiepileptic drugs), presence of any skull defects, and other relevant medical information should also be included. If there are any modifications from standard electrode placements, the changes should be noted.
2. All EEG recording systems should be calibrated at the beginning and end of the procedure. In analog systems, all channels should be calibrated by connecting the same pair of electrodes at the beginning of the session (biological calibration), though this is not necessary in digital systems. Repeat calibration should be performed if in doubt. Calibration is a mandatory step for all EEG recordings, which provides the interpreter with standards for estimating the scale of amplitude. Moreover, the sensitivity of EEG equipment, low-pass and high-pass response, level of noise, and arrangement and damping of the recording pen should be assessed. During biological calibration, frontooccipital derivation should be applied in order to evaluate both movements in the delta-wave range (i.e., eye movements) as well as fast alpha range activities. Technologists should carefully observe the first 30 second of the reference montage without the notch filter.
3. For routine EEG recording, the sensitivity of EEG should be set to 5–10  $\mu\text{V}/\text{mm}$ . Sensitivity is defined as the ratio between amplitude from the input voltage and trace deflection, and is represented as  $\mu\text{V}/\text{mm}$ . A sensitivity of 7  $\mu\text{V}/\text{mm}$  is commonly used, which indicates that if the calibration signal is 50  $\mu\text{V}$ , the pen deflection is 7.1

mm. If the sensitivity decreases from 7 to 10  $\mu\text{V}/\text{mm}$ , the amplitude of EEG waveform decreases. In contrast, if the sensitivity increases from 7 to 5  $\mu\text{V}/\text{mm}$ , the amplitude of waveform also increases. If the sensitivity is less than 10  $\mu\text{V}/\text{mm}$  (i.e., 20  $\mu\text{V}/\text{mm}$ ), meaningful low-amplitude activity may be undetectable. Furthermore, when sensitivity is greater than 5  $\mu\text{V}/\text{mm}$ , normal EEG signals might have amplitudes exceeding the range and be recorded as abnormal signals. A sensitivity of 5  $\mu\text{V}/\text{mm}$  indicates that EEG recordings of 1 mm require 5  $\mu\text{V}$  of the input voltage (hence, movement of 10 mm will require 50  $\mu\text{V}$ ). In digital systems, this straightforward physical correlation of sensitivity is lost because different monitor sizes utilize different recording scales. It is important to prevent distortion of recorded signals during calibration for routine recordings. Appropriate adjustments are necessary if the EEG activity from planned sensitivity is too high or too low in amplitude.

4. EEG signals in digital recordings are filtered at two levels. The first level of filtering occurs at the in the actual amplifier prior to digitization of the incoming signal (analog filter). The second level of filtering involves the application of digital filters prior to displaying the digitized data. In standard EEG recordings, low-frequency filters should have a time constant equivalent to 0.16 s, and should be no higher than 1 Hz. The high-frequency filter should not be lower than 70 Hz. However, a horizontal resolution of  $\geq 1,400$  pixels is required to visualize frequencies as high as 70 Hz on a monitor. The interpreters should be aware of the probability of signal loss at high-frequency resolutions, as well as the possibility of low-frequency distortion due to spatial aliasing. Adequate use of high-frequency or low-frequency filters with detailed annotation may be helpful, although filter controls should be used selectively and cautiously.
5. A 60-Hz notch filter can distort or attenuate epileptiform discharges, and this should be applied only if all other methods to diminish 60 Hz interference have failed.
6. The speed of recording is typically set at 3 cm/second on paper EEG systems. A display of 10 to 20 seconds/page should be used for digital monitors. Neonatal EEG or other special cases can adopt a display of 15 to 30 seconds/page.
7. Routine EEG sessions should include at least 20 minutes of data recording. Technologists should assess the EEG re-

recording using at least three different montages, including a minimum of one bipolar and one reference montage. Without any technical difficulties, an absolute minimum of 20 minutes of artifact-free recording (including activating procedures) is required to assess baseline EEG activity. Within the given limit, longer EEG recording increases the chances of identifying abnormalities such as epileptiform discharges.<sup>7,8</sup> Experiences reported by different epilepsy centers indicate that at least 20 min of noise-free, high-quality EEG recording is required to provide a fundamental assessment of EEG activity. If photic stimulation, hyperventilation, and sleep are included, the recording time of EEG increases.

8. EEG data should be acquired for periods in which the patient's eyes are both open and closed, as long as the patient is able to cooperate. Differences in rhythms obtained during the eyes-open and eyes-closed states should be compared. If the patient is unable to cooperate or does not do so, his or her eyes should be opened and closed manually. Photic stimulation with dimmed light must be applied at a distance of at least 30 cm from the patient's face, prior to hyperventilation or after all hyperventilation-associated changes disappear. An electrocardiogram (ECG) channel should be applied on one EEG channel to differentiate sharp waves from pulse or ECG artifacts.
9. Hyperventilation is mandatory unless there are other medical problems (i.e., recent intracranial bleeding, severe cardiovascular or respiratory disease, or patient's status that prevents voluntary cooperation). This should be performed for at least 3 min, and EEG must be recorded for at least 1 min after the cessation of hyperventilation (sometimes longer). To assess the effect of induced hyperventilation, recordings should last at least 1 minute and utilize the same montage as that used prior to hyperventilation. The EEG technologist should record the quality of patient effort during hyperventilation recordings.
10. EEG activity during sleep must be recorded, if possible, along with EEG arousal. Recording during drowsiness and sleep is very useful for obtaining additional, relevant information.<sup>9,10</sup> Technologists should note the patient's sleeping status in medical records. Sleep recording is particularly essential for patients with suspected epileptic seizure disorders. Sleep deprivation is necessary to increase the frequency of detecting epileptiform discharges.<sup>11,12</sup>
11. The patient's level of consciousness (i.e., awake, drowsy, asleep, and comatose) and any changes should be annotated on the EEG recording by the technologist. The patient's comments, movements, clinical seizures, and absence of seizures must also be recorded in detail. Careful observation and documentation of the patient are very important especially in cases of atypical EEG activity. If abbreviations are used, these must be uniform and standardized so that they may be easily recognized by the interpreter. If the patient is semiconscious or unconscious, visual, auditory, and somatosensory stimulations should be applied. The types of stimuli as well as responses to stimulation should be recorded. The technologist should describe changes in the patient's clinical status in detail, as these may further aid in clinical diagnosis. At least some portion of the recording should be performed while the patient is maximally alert.
12. Special procedures that can be dangerous to the patient should be performed only under the supervision of a physician, and with appropriate first aid/emergency resuscitation kits readily available. Further, obtaining informed consent of the patient or legal guardian is recommended.
13. If critical events including the presence of electrographic or clinical seizures occur during EEG recording, the technologist must notify the interpreting neurophysiologist of the results.
14. EEG for the assessment of cerebral death (cessation of cerebral function) requires special procedures and cautions. Refer to ACNS Guideline 6 for further details.<sup>13</sup>
15. Commonly performed in many laboratories, simultaneous video recording with EEG is useful for identifying semiology as well as artifacts.

### Conflict of Interest

We have no affiliations with or involvement in any organization or entity with any financial interest, or non-financial interest. The authors report no disclosures.

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