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Consensus Statement on Continuous EEG in Critically Ill Adults and Children, Part II: Personnel, Technical Specifications and Clinical Practice

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Part I of this consensus statement described the most common indications for CCEEG in adults and children. Part II covers technical aspects of CCEEG, such as qualifications of personnel performing and interpreting CCEEG, equipment, documentation, and safety. Part II also addresses commonly used CCEEG techniques for specific indications in adults and children.

CCEEG is a rapidly evolving technology, and this statement addresses only current consensus-based recommendations for CCEEG. At this time, there is inadequate data on the impact of CCEEG on clinical outcomes to develop practice standards based on strong evidence, but existing evidence is summarized within this document. Because NCS and other secondary brain injuries are often completely unrecognized without CCEEG, this document emphasizes that delayed recognition is better than no recognition. In particular, the term “monitoring” usually does not imply continuous real time analysis and reporting of the EEG. Due to resource limitations, CCEEG is typically acquired continuously and reviewed intermittently by neurodiagnostic technologists (NDTs) for technical quality and changes in EEG patterns and also intermittently by electroencephalographers for interpretation and clinical correlation. The decision to initiate CCEEG, frequency of review, and communication of results to ICU caregivers are determined by local resources, local monitoring indications, CCEEG findings, and the patient's clinical status.

V. QUALIFICATIONS AND RESPONSIBILITIES OF CCEEG PERSONNEL

A. CCEEG Electroencephalographer

1. The CCEEG team should be supervised by a physician with training and experience in clinical electroencephalography and specifically in CCEEG.
 - a. For hospitals without CCEEG electroencephalographers on staff, CCEEG may be outsourced to external companies with appropriately trained staff, or by establishing oversight policies and procedures by CCEEG electroencephalographers within a hospital network system.
2. Education / certification
 - a. Physician licensure in the state or country in which CCEEG is performed.
 - b. Privileges to interpret EEGs in the hospital in which CCEEG is being performed.
 - c. Appropriate training and/or certification:

- 1) Certification in Clinical Neurophysiology (e.g. American Board of Psychiatry and Neurology (ABPN) in the subspecialty of Clinical Neurophysiology or American Board of Clinical Neurophysiology (ABCN)), OR
- 2) Completion of 1 year fellowship training in clinical neurophysiology with concentration in EEG (at least 6 months full time) and at least 3 months of CCEEG, OR
- 3) Certification in Epilepsy (e.g. ABPN in subspecialty of Epilepsy) after completion of 1 year fellowship training in clinical neurophysiology or epilepsy which includes at least 6 months full time exposure to EEG and at least 3 months of CCEEG, OR
- 4) Certification in Neurocritical Care (e.g. United Council for Neurologic Subspecialties (UCNS), with at least 6 months post-residency full time training in EEG and at least 3 months of CCEEG, OR
- 5) Equivalent experience

d. Experience

- 1) Supervised interpretation of routine EEG, video EEG, and CCEEG. To ensure adequate exposure to a variety of EEG patterns, we suggest 500 EEGs (including routine, ambulatory, and video-EEG for epilepsy) and 100 CCEEG studies.
- 2) Expertise in the operation of CCEEG equipment, including technical aspects of recording in the ICU, electrical safety, equipment troubleshooting, data recording and storage, and computer networking.
- 3) Expertise in interpretation of CCEEG and video data generated in the ICU, including recognition of seizures and status epilepticus, ischemia, and the effects of acute brain injuries and drugs on EEG activity. Experience beyond routine EEG interpretation is necessary because much of the analysis involves complex rhythmic and periodic patterns and artifacts seldom encountered in a standard EEG laboratory. The analysis of CCEEG requires the simultaneous interpretation and correlation of EEG data with behavioral events and other simultaneously recorded physiologic data.
- 4) Expertise in the use, yield and limitations of quantitative EEG graphical trending.

3. 3. Responsibilities

- a.** Development of policies and procedures related to CCEEG (medical director of CCEEG program only).

- b. Analysis of pertinent segments of EEG, QEEG, and behavioral data reviewed in appropriate formats.
- c. Timely communication of important EEG changes to the clinical management team, or other suitable integration of the EEG and clinical management teams.
- d. Preparation of daily written CCEEG reports.
- e. Final interpretive synthesis of CCEEG data with diagnostic and pathophysiological formulations.

B. CCEEG Neurodiagnostic Technologists (NDT) and Associated Personnel

1. CCEEG should be performed by appropriately trained, certified, and supervised NDTs.
2. The schema provided is a suggestion for NDTs working in the ICU. Adaptations are expected based on institutional conditions, staffing, and workflow requirements. We recommend that at least one NDT performing CCEEG have training, credentialing, and/or experience at the level of Neurodiagnostic Technology Specialist I ICU (IV.B.5).
3. Neurodiagnostic Technologist I (NDT I, Trainee)
 - a. Education / certification
 - 1) Associate's degree OR
 - 2) Enrolled in Neurodiagnostic program
 - b. Responsibilities
 - 1) Maintains recording integrity (replaces or re-gels electrodes, restarts studies, troubleshoots basic equipment errors).
 - 2) Performs 10/20 measure and applies electrodes under the direct supervision of NDT III or NDTS I-II (see below) according to facility policy.
 - 3) Removes electrodes, including collodion removal with acetone, under supervision.
 - 4) In emergency situations, may independently place limited electrode arrays using premeasured caps or nets, with self-adhesive, disk, or needle electrodes.
4. Neurodiagnostic Technologist II (NDT II)
 - a. Education / certification
 - 1) Meets ASET – The Neurodiagnostic Society National Competencies for Performing an Electroencephalogram.

- 2) If EEG Assistants are utilized, the center should have a written policy and procedure describing the types of tasks that can be performed, as well as requirements for training and determination of competency (Seiler, Fields et al. 2012).

c. Responsibilities

- 1) Typical tasks include reapplying or re-gelling loose or detached electrodes, removing electrodes, performing emergency EEG using limited electrode array templates or caps, or monitoring video recordings for changes suggestive of clinical seizures.

9. CCEEG Observer

- a. CCEEG Observers are not NDTs and cannot substitute for the EEG review functions of qualified NDTs. Their role is to continuously review video and sometimes quantitative EEG trends and serve as “first responders”, notifying trained NDT and physician staff about clinical and/or trend changes. The EEG Assistant should be able to communicate with a qualified NDT, preferably NDTs, who can connect and review EEG remotely.

b. Education / certification

- 1) High school diploma or equivalent.
- 2) Training in recognition of clinical ictal behavior and interaction with patients during seizures to assess level of consciousness.
- 3) May include training in recognition of important changes on graphical displays of quantitative EEG.
- 4) May include training in maintaining recording integrity (reapplying or re-gelling loose or detached electrodes).

c. Responsibilities

- 1) Patient and quantitative EEG observation (direct or several patients at a time via video monitoring) to identify and note ictal events, interact with patients during seizures, and alert appropriate personnel (e.g., physician, NDTs, nursing staff) to the occurrence of changes in quantitative EEG trends.
- 2) Adjust video cameras to keep patient in view and ensure that EEG and video is continuously recorded, calling appropriate personnel to assist when problems occur.

- d. ICU nurses may serve in this role, including alerting physicians to events that require physician review and changes in patient care.

VI. CCEEG MONITORING EQUIPMENT

A. The committee recommends that CCEEG meet the technical specifications described in ACNS guidelines for performing clinical EEG in adults and children (Society 2006b, Society 2006a).

B. Electrodes

1. Disk or cup electrodes (gold, silver, or silver chloride) are typically used for CCEEG. Electrodes with a central hole are best, to permit periodic refilling with electrode conductive gel.
 - a. When possible, CT- and/or MRI- compatible electrodes should be used, especially if the patient is likely to require repeated neuroimaging studies (Vulliemoz, Perrig et al. 2009). More than 50% of patients will require neuroimaging with MRI or CT during the course of CCEEG monitoring. These electrodes (e.g. conductive plastic electrodes, subdermal wire electrodes) can remain in place during imaging, reducing time spent removing and reapplying electrodes, and may also reduce skin breakdown caused by frequent electrode removal and reapplication.
 - b. For CT compatibility, electrodes must be low density, non-metal to avoid “starburst” artifact, and are typically carbon or silver impregnated plastic. Connectors for some electrodes, including needle electrodes, may contain metal that causes streak artifact on CT or degrades the quality of angiograms.
 - c. For MRI compatibility, specialized electrodes and techniques are needed to avoid thermal or radiofrequency burns. These include non-magnetic electrodes, short electrode wires, specialized connectors, and careful avoidance of electrode wire coils (Mirsattari, Lee et al. 2004).
2. Subdermal needle electrodes. Single use disposable stainless steel needle electrodes can be applied rapidly and do not require scalp abrasion. Needle electrodes have inferior recording characteristics (attenuate low frequency signals) and pose a risk for needle-stick injury to ICU personnel if dislodged, They may be appropriate for rapid application and brief recording in some comatose patients (Kolls, Olson et al. 2012), but are generally not recommended for prolonged CCEEG recordings. Needle electrodes may cause some artifact on CT and angiography and are not MRI compatible.
3. Subdermal wire electrodes (SWE). SWE are single use disposable Teflon-coated silver wire with a 3-5mm silver chlorided tip (Mirsattari, Lee et al. 2004, Ives 2005, Vulliemoz, Perrig et al. 2009). They may reduce skin breakdown and provide superior recording characteristics compared to disc electrodes for patients requiring very prolonged CCEEG monitoring (Martz, Hucek et al. 2009). They cause little artifact on CT and angiography and can be MRI compatible with specialized connectors.

4. Electrode cap and/or template systems may be used when rapid initiation of EEG electrodes is essential or when NDTs are not immediately available. Caps must be disinfected between each use, may increase risk of pressure injury from electrodes, and may be limited by the presence of scalp wounds or other cranial monitoring devices. Single-use disposable templates can be placed quickly and reliably and limit infection risk.
5. Scalp electrodes should be applied with proper infection control policies and procedures. Disposable single-use electrodes should be considered, especially for patients with scalp wounds or recent neurosurgical procedures. These electrodes are more expensive than traditional EEG electrodes.
6. Intracranial electrodes. Subdural grid or strip electrodes for CCEEG monitoring have been used to identify electrographic seizures and cortical sustained depolarization in critically ill patients, but are not in routine clinical use (Hartings, Bullock et al. 2011, Hartings, Wilson et al. 2013). Intracranial depth electrodes have been used in combination with FDA-approved intracranial monitoring devices, but are not in routine clinical use (Waziri, Claassen et al. 2009, Stuart, Schmidt et al. 2010, Stuart, Waziri et al. 2010).

C. CCEEG Acquisition Machines

1. CCEEG amplifiers, analog to digital converters, central processing units, software, and monitors should meet ACNS recommended specifications (Society 2006d, Society 2006b, Society 2006a), with the following additional points for CCEEG.
2. Amplifiers. Wirelessly connected amplifiers can be placed at a distance from the patient's head and may be preferred in the cluttered ICU environment. Some amplifiers are battery-powered and contain internal storage, allowing continued EEG recording even when patients leave the ICU for other procedures.
3. CCEEG acquisition computers should have sufficient processing capability to perform simultaneous EEG and video acquisition, quantitative EEG analysis, and spike/seizure detection.
4. Hard drive capacity should be sufficient for storage of at least 24 hours of continuous video and EEG data. Most currently available systems far exceed this capability. Typical equipment can record and locally store 5-7 days of 32 or more channels of EEG plus digital video.
5. CCEEG acquisition machines can be either fixed or portable. Fixed installations often have advantages in terms of video recording, as cameras are mounted high on the wall. EEG equipment is also away from the patient and out of the way of ICU personnel. However, when EEG machines are fixed, patients requiring CCEEG have to be moved into rooms with the EEG equipment, which can result in delays in initiation of monitoring. Portable carts should have a small footprint to minimize disruption of workflow in the ICU room.
6. Video and cameras. Concurrent synchronized video recording is recommended for CCEEG. Video recording allows correlation of clinical behavior (e.g. seizures,

changes in level of alertness, identification of alerting stimuli) with EEG features. Review of video is also an excellent method for identification of artifact in CCEEG studies (Tatum, Dworetzky et al. 2011).

- a. Equipment for video recording varies extensively in features, picture quality, and cost, ranging from small portable monochrome cameras to fixed multi-camera installations with full remote control capabilities. Patients in the ICU are not likely to move themselves off camera, so fixed wide-angle cameras may be a low-cost solution. Accurate resolution of fine motor movements or subtle seizures, however, will likely require high resolution color cameras with the ability to move and zoom the camera to body regions of interest. The video stream is time synchronized with the EEG data.
 - b. Cameras should be mounted on the wall or on a tall pole to allow the patient to be visualized even when bedside caregivers are in the room.
 - c. IP addressable cameras allow remote pan/tilt and sometimes focus/zoom from remote locations over standard network cable. This reduces costs, as no specialized cables need to be run. IP cameras may be appropriate for both fixed and mobile acquisition machines.
 - d. Video should be recorded in high resolution as feasible with appropriate compression algorithms for sufficient storage and transportability. MPEG-4 format at 320×240 or 640×480 pixel resolution is commonly used. Full HD quality video is now available, but generates extremely large file sizes (12-20GB/24 hours) and is often not needed for CCEEG recordings.
7. Audio recording. In addition to the video image of patient behavior, an audio recording can alert monitoring technologists to clinical episodes and allow assessment of behavior and neurological function as related by CCEEG personnel attending to the patient during the episode.
 8. Because the ability to remotely view CCEEG is essential, all machines should have network connectivity, network interface card 100 mbit/sec minimum. Rapid EEG and review of video will usually require at least 1 gbit/sec. Wireless connectivity can be used when wired network connections are not available, but may lack sufficient bandwidth for transfer of video recordings.
 9. Event marking. Systems should include a patient event button for patient, family, and staff to push when clinical events occur, as well as ability to type comments directly onto the EEG tracing.
 10. Isolated power supplies and electrically isolated jack boxes should be utilized to protect electrically-sensitive patients from injury.
 11. User-friendly hardware and software features can substantially improve the efficiency and quality of CCEEG. The following features may be helpful and should be considered when evaluating and purchasing EEG equipment.

- a. Ability for ICU personnel to annotate ongoing records. Simplified user interfaces and touchscreen displays often improve usability for ICU personnel.
- b. Artifact / bad channel displays.
- c. Automatic recovery mode (if machine is accidentally unplugged or malfunctions, automatically restarts and re-acquires data when turned back on).
- d. Automatic start / stop study (by time or by number of hours recorded).
- e. Event detection. Methods of detection of clinical events and seizures include: 1) Patient or nurse activated pushbuttons as above; 2) automated spike and seizure detection programs, although these have not been validated for ICU patients; 3) graphical displays of quantitative EEG (trends, see Section V.E), and 4) alarms or automated alerts for events via audio, video, pager, or e-mail.
- f. Security. All computers should be HIPAA compliant and meet local Information technology security standards. Password-protected transparent screen locks can prevent non-ICU personnel from interfering with recording but still allow viewing of ongoing recording. Acquisition computers left in patient rooms should be locked to prevent access to hard drives and be secured with cable locks to the acquisition machine frame. Laptop computers and external drives should be locked and encrypted.

D. Equipment for Polygraphic Data Acquisition

1. Polygraphic and multimodality data may be useful in interpretation of CCEEG, recognition of artifacts, and confirmation of changes in brain function by correlation with other physiologic parameters (Vespa 2005, Wartenberg, Schmidt et al. 2007, Tatum, Dworetzky et al. 2011, Miller 2012). Physiologic data streams should be time synchronized with EEG. The details of data acquisition for physiologic parameters other than EEG are beyond the scope of this consensus statement.
2. Types of polygraphic or multimodality recording include: electrooculogram (EOG); electromyogram (EMG); electrocardiogram (EKG); body movement monitors or actigraphs; temperature; blood pressure (noninvasive or invasive); respiratory effort; respiratory air flow; oxygen saturation; intracranial pressure; transcranial Doppler; evoked potentials; brain tissue oxygenation; cerebral microdialysis, and near infrared spectroscopy.
3. Integration of polygraphic data with CCEEG. Lack of standardization and data exchange formats makes multimodality data collection and storage difficult. Electrodes, specialized devices, or transducers can be connected directly to the CCEEG machine. This is the most common way to record EOG, EMG, and EKG. Specialized devices and transducers may require DC amplifier inputs. Most other physiologic data are obtained and displayed on ICU monitors, so use of another

device connected to the CCEEG machine is redundant and potentially costly. Alternatively, the output from ICU monitoring devices can be duplicated and output to the CCEEG machine. This may require specialized cables to output signals from ICU monitors to CCEEG machines. A variety of vendors make ICU monitors, and there is little standardization of device types and inputs. Post-hoc or real time integration of data files from ICU monitor and CCEEG machine usually requires custom software solutions or data export into existing open source formats.

E. EEG and Video Review Machines

1. Review is typically performed at a review station or computer separate from acquisition machines.
2. Display monitors for review. The current optimal standards are 1600×1200 pixels with a screen diagonal size of 20 inches or more. Dual monitors may be helpful for concurrent display of raw EEG tracings and quantitative EEG trends. Monitors for remote review may have lower resolution, but these may introduce aliasing artifacts (Epstein 2003).
3. Software features useful for review
 - a. Remote control capabilities, including pan, tilt, zoom (PTZ) camera control and the ability to review and control live ongoing studies and alter recording parameters from remote locations.
 - b. Ability to filter EEG data by type of events.
 - c. Databases and report generation software. These allow efficient organization of patient and study information, facilitate archiving and retrieval of data, allow reports to be saved as part of the EEG record, and, if HL7 compliant, can be interfaced with electronic medical records.
 - d. Security. Systems should be HIPAA compliant and meet local Information technology security standards.

F. Central Monitoring Equipment

1. Nurse or technologist monitoring stations are specialized hardware and software solutions which allow simultaneous viewing of video streams, and sometimes EEG and quantitative EEG trends, for a number of patients on a single monitor or cluster of monitors. These systems frequently include software to allow movement of cameras, audio and/or video alerts when patient pushbuttons are activated or automated seizure detection algorithms, and intercoms for interaction with patients during clinical events. Although no studies have directly addressed the clinical utility of central monitoring, the fact that many patients can be monitored simultaneously likely decreases the costs of monitoring. See section V.E.6 for further details.

G. Networking, Remote Access, and Data Storage Equipment

1. Because the goal of CCEEG is to rapidly identify seizures and ischemia, CCEEG data should be available for review by personnel both within and outside the hospital. This requires robust networking and remote access capabilities.
2. Hospital network. The ICU should be supported by a robust network backbone with sufficient capacity to transmit EEG and video data from acquisition systems and/or servers to review stations without perceptible degradation of review speed. The backbone should be fully redundant, so that clinical care CCEEG monitoring services are not vulnerable to single component failures. Fully hard-wired networks are preferred; the network interface speed for acquisition devices should be at least 100 megabits/sec (mbps). Wireless connection may be acceptable, provided that the hospital's wireless infrastructure is adequate to support high-reliability continuous data transfer at speeds sufficient for video/EEG monitoring. Wireless networks designed for applications with lower bandwidth and reliability requirements, such as record keeping and administrative functions, may be inadequate. The bandwidth of a wireless access point is shared by all simultaneously connected devices (similar to a hub on a wired network), and permanent as well as mobile (e.g. x-ray machines) physical obstacles can create "dead spots" where wireless communication can fail, or can be slow or unreliable; the quantity, type and positioning of wireless access points in the ICU should be sufficient to mitigate these concerns.
3. Acquisition machines. If EEG/Video data are stored in real-time to a central server (rather than locally on the acquisition machine), the acquisition system should be able to automatically detect loss of ability to write to the server, and seamlessly revert to local storage with no loss of data. Ideally, the system should also be able to automatically detect restoration of connectivity, upload locally buffered data, and seamlessly resume real-time data upload.
4. Remote access. Each hospital will likely have specific hardware and software available for remote access solutions. Because remote access potentially poses a risk to security of patient data, hospitals typically impose stringent security protocols governing use of these systems. Solutions vary widely in ease of implementation and cost. CCEEG programs should work with their hospital's information technology (IT) department to determine which solution has optimal ease of use, security, and cost.
 - a. Ad-hoc secure remote desktop connections. Software packages such as Go-To-My-Pc or Log-me-in can provide a remote PC (or tablet computer) with a real-time copy of the screen of a desktop CCEEG reading station in the hospital. These systems can be secure, but this security is critically dependent upon proper implementation; if this type of system is used for remote CCEEG monitoring, it is suggested that it be implemented by, or under the supervision of, the hospital's IT department.
 - b. Virtual private network (VPN). Hospitals commonly use VPNs to provide for remote access to resources within the institution's network. A VPN

establishes a secure encrypted “tunnel” from the remote computer, through the Internet, to behind the hospital's firewall, so that the outside computer can appear to be part of the hospital's network. Remote CCEEG monitoring may be implemented over a VPN in 2 ways:

- 1) The actual EEG data are sent over the Internet, and displayed on the remote computer by standard review software. Each remote computer must have the EEG review software installed. Because Internet speeds are likely to be slower than hospital network speed, on-line real-time VPN review may be slow. Downloading the EEG files to the local computer prior to review allows for fast review speed.
 - 2) Remote desktop software may be used to provide a remote screen view, much like with secure remote desktop connections, above, but relying on the VPN tunnel for security. A variety of remote desktop solutions are available, including the RDP protocol built into Microsoft Windows.
 - c. Server-based remote desktop systems. Systems such as Windows Terminal Services or Citrix provide remote desktop access, but to “virtual desktops” running on the hospital's server. The EEG review software runs on the server, and only screen images are sent over the Internet. These systems can provide reliable, centrally administered review platform, and offer greater security than a VPN. They can be costly, including the servers and software license fees.
5. Data storage equipment. File servers can provide a central repository for CCEEG and video data files, allowing multiple users to connect to the same data from multiple locations. CCEEG file servers typically run database software (generally supplied by the EEG vendor) that keeps track of patient identifying information and data locations. File servers should have adequate storage capacity (data generated in 24 hours by 1 CCEEG acquisition machine \times number of acquisition machines \times number of days data are stored before archiving). Example: 12 GB/day (video + EEG) \times 8 machines \times 30 days = 2880 GB or ~ 3 terabytes (TB). Servers employ specialized hardware, including arrays of high-speed disk drives, to provide reliable high-speed access to large quantities of data, even under conditions of heavy load. Servers selected for CCEEG monitoring should be specified to have sufficient and data throughput to support rapid, uninterrupted EEG/video data review, even when the maximum number of simultaneously active acquisition and review stations are in use. Servers should also be specified to provide safeguards against data loss. These include appropriate configuration of disk arrays to provide data redundancy, as well as off line backup.
 6. Archiving equipment. Video data accounts for the bulk of CCEEG data storage requirements, particularly with newer high-resolution cameras; when a study is ready for archiving, most video data typically does not need to be retained, and can be discarded. Depending upon available resources and the institutions archive

storage requirements, archived studies may be retained online, either on the primary data server or on a lower performance online storage device, or offline using external DVDs or hard drives. Archiving software should have the capability of operating automatically, without negatively impacting server performance for CCEEG review functions. It should include the ability to export data to long-term storage media and to export to open-source EEG data formats. It is important to consider applicable data retention requirements when implementing CCEEG data archive solutions. See section V.H: CCEEG Data Storage Protocols for archiving procedures.

VII. CCEEG PROCEDURES

A. Patient Selection and Triage

1. CCEEG programs should have written pathways outlining the indications, urgency, and duration of CCEEG, based on typical patient populations encountered and availability of local resources. Even in well-established CCEEG programs, availability of staff and equipment may limit the number of patients who can be recorded at one time. Written protocols can help to facilitate CCEEG monitoring, ensuring that patients who meet criteria for CCEEG are referred for testing and establishing parameters for starting and stopping tests. Pathways for CCEEG monitoring are generally developed by a team including both electroencephalographers and critical care physicians. They define patient populations, by disease and by illness severity, in which CCEEG should be ordered and initiated in a specific hospital setting, as well as the typical duration of CCEEG.
2. Example pathways for patient populations in whom CCEEG is typically recommended can be found in the online Supplement Table 2.

B. Initiation of CCEEG

Under ideal conditions, CCEEG should be available 24 hours a day seven days per week, with electrodes applied and EEG recorded by NDTs as described in section III.B, with rapid interpretation by an experienced electroencephalographer. Unfortunately, CCEEG is not continuously available in all hospitals, and may take several hours to initiate, record, and interpret even when the service is available (Quigg, Shneker et al. 2001, Abend, Dlugos et al. 2010, Sanchez, Arndt et al. 2013, Sanchez, Carpenter et al. 2013). Once a CCEEG program is established, demand for off-hours and urgent EEG increases and usually requires that an NDT technologist be in the hospital for at least the majority of the day, including weekends.

- a. In some cases, NDT technologists may take call from home. If so, patient selection written pathways should clearly indicate which indications justify calling in an NDT to initiate CCEEG.
- b. Limited electrode arrays can be applied by trained neurology residents, nursing staff, or patient care technologists, but interpretable recordings may be difficult to obtain by non-NDT staff. Template systems, such as elastic nets with holes for

standard electrode positions, or pre-gelled “peel-and-stick” plastic strips, may improve EEG quality, time to study completion, and overall costs (Ziai, Schlattman et al. 2012, Kolls, Lai et al. 2014).

- c. Additional research is necessary to determine the utility and cost effectiveness of providing continuous availability of CCEEG.

Electrode types

- a. A variety of different types of electrodes is available for use in the ICU (Section IV.B.). CCEEG programs should consider electrode cost, ease-of-use, time for application, imaging compatibility, durability, and recording characteristics when selecting electrodes for ICU patients.
- b. Adoption of a uniform electrode type may be helpful.
 - 1) CCEEG staff can more easily train nurses and other staff about electrode application, procedures for emergency removal, and safety.
 - 2) Safety for neuroimaging, particularly MRI, is enhanced with uniform electrodes.

Electrode application

- a. Disk electrodes. Application by electrode paste alone is not recommended. Collodion technique is the preferred method to ensure a stable long-term recording, but may not be possible in all ICU locations. Collodion use is restricted in some ICUs due to inadequate ventilation. Collodion is typically removed with acetone, which poses a risk for injury to eyes and skin of both patients and staff, as well as damage to other intracranial monitoring devices, some plastics, and tubing. EC2 paste, Tegaderm, and cyanoacrylate may substitute for collodion. Disk electrodes may cause pressure breakdown in comatose patients undergoing prolonged CCEEG, especially in posterior head regions. A cushion or pad may be used under disk electrodes to reduce pressure breakdown of the skin, and the head frequently rotated and elevated with a neck roll to reduce prolonged pressure on the same scalp locations.
- b. Subdermal needle electrodes. The scalp is cleaned thoroughly with presurgical scrub. Needle electrodes are inserted just beneath the skin, parallel to the surface of the scalp. The full length of the needle should be embedded. Needle electrodes should be secured with collodion or EC2 paste. They are often used as part of a rapid-application kit, and can be secured to the head net. Needle electrodes are not appropriate for awake patients, infants, young children, patients with suspected viral hepatitis or Creutzfeldt-Jakob disease (CJD), or prolonged recording.
- c. Subdermal wire electrodes. Subdermal wire electrodes are inserted using a 25- or 27-gauge introducer needle, inserted 0.5 cm just beneath the skin, parallel to the scalp. The wire is then held in place while the needle is removed. The external wires should be coiled to relieve tension and fixed to the scalp using collodion, EC2 paste, cyanoacrylate, or Tegaderm adhesive.

- d.** Procedures for patients with non-intact skin. Disposable scalp electrodes may be used, but can be expensive. Electrode caps should not be used on non-intact skin. Care should be taken to avoid contamination of surgical wounds, intracranial monitoring devices, or other scalp lesions. In many cases, electrode positions may need to be adjusted to avoid scalp lesions; the homologous electrode over the contralateral hemisphere should also be moved.

Number of electrodes

- a.** Standard CCEEG requires a minimum of 16 electrodes placed according to the 10-20 International System, with placement designed to optimize brain regions sampled (e.g. Fp1, Fp2, C3, C4, O1, O2, T3, T4). If fewer than sixteen electrodes are used, interpretation of CCEEG may be limited by inadequate spatial sampling, inability to distinguish artifact from cerebral activity, and poor quality or uninterpretable studies if any of the few electrodes are dislodged or are contaminated by large amounts of artifact. Studies using hairline and subhairline montages had a sensitivity for seizures of 54 to 72% compared to full EEG (Kolls and Husain 2007, Young, Sharpe et al. 2009, Tanner, Sarkela et al. 2014).
- b.** Fewer than 16 EEG channels may be used for rapid screening of EEG in emergency situations, but adequate EEG recording (i.e. > 16 electrodes) should be instituted as soon as possible.

Extracerebral electrodes. At a minimum, EKG should be recorded with every CCEEG study. EOG, EMG, and respiratory channels (airflow, respiratory effort, and oxygen saturation) are also commonly used. Other physiologic parameters (blood pressure, intracranial pressure, cerebral tissue oxygenation) are often recorded in ICU patients. Integration of these signals with EEG (multimodality monitoring) may improve recognition of neurologic dysfunction and determination of etiology.

Montages. Montages should be appropriate for the abnormalities anticipated.

Suggestions for montages can found in other ACNS guidelines (Society 2006c).

- a.** NDTs should make note of any skull defects including craniotomies, intraventricular drains, bolts and burr holes and indicate this in the EEG record and report. If the standard 10-20 montage needs to be modified due to skull defects or intracranial equipment, it should be modified symmetrically with adjustment of the corresponding contralateral electrode. This should also be documented in the EEG record and report.

EEG quality. Prior to initiation of recording, the NDT should perform an impedance check and evaluate for presence of artifacts. Since modern amplifiers have high input impedance, electrode impedances less than 10,000 ohms are acceptable.

Video and audio. Cameras should be adjusted to allow a full body view of the patient, and lighting adjusted to obtain acceptable video quality. Bedside caregivers and family should be encouraged to verbally describe any clinical events which occur.

NDTs should collect relevant clinical data from ICU staff and the medical record, such as patient history, level of consciousness, recent procedures, medications (including

sedatives, paralytics, and ASDs), and other monitoring techniques in use. NDTs should prepare a brief summary of clinical data.

NDTs should remain at the bedside for the first 20 minutes of recording to evaluate for EEG patterns requiring urgent interpretation, examine patient behavior, and ensure acceptable data quality. During this time, NDTs should perform activation procedures to test reactivity of the EEG: visual stimulus (shine light in patient's eyes), auditory stimulus (clap hands or call name), tactile stimulus (shake limb, nasal tickle), and painful stimulus (sternal rub, nail bed pressure). There is no data regarding the optimal method of reactivity testing.

NDTs should instruct ICU staff on operation of CCEEG equipment, including type of electrodes used and imaging compatibility, techniques for emergency removal of electrodes if needed, use of the event button and camera controls, instructions for annotating the EEG record or keeping a paper log for clinical events, identification of common artifacts, and procedures for contacting EEG staff if technical problems arise.

C. Daily Maintenance of CCEEG

1. NDTs should collect relevant interim clinical data from ICU staff and prepare interim clinical notes as above.
2. NDTs should review operation of CCEEG equipment with ICU staff as needed daily.
3. CCEEG recording quality should be checked at least twice daily to identify and correct electrode and other technical artifacts. Impedance should be checked daily, or more often if recording characteristics change. Refilling of the electrodes with conductant gel should be performed as necessary to maintain low impedance. Digital algorithms can be used to identify channels with probable electrode artifact and display the “bad electrodes” on the bedside EEG machine or automatically alert EEG personnel that data quality has deteriorated. If available, ICU nursing staff should be trained to use these displays.
4. The patient's scalp should be inspected daily for evidence of skin breakdown or infection. Programs should have written protocols describing how and when to check for skin breakdown, how to document, to whom skin breakdown should be reported, and methods of treatment.
5. Clinical and EEG reactivity should be assessed daily. The presence of any sedating medications and the timing of their administration should be recorded. Optimally, reactivity testing is performed after fixing any electrode problems. Because fixing electrodes is a type of stimulation, reactivity should be assessed from the time the patient is first stimulated. The stimulus used for reactivity testing should be recorded, and an institutional protocol for reactivity assessment may be useful. For certain indications, such as monitoring for ischemia, more frequent checks of reactivity are helpful and can be incorporated into nursing assessments and annotated on the EEG record.

D. Electrode Removal and Infection Control

1. Disk electrodes. Collodion is typically removed with acetone, which can cause injury to patient's eyes and mucous membranes. Acetone can also dissolve some plastics and tubing used in other medical devices, such as ECMO tubing and intraventricular catheters. A non-acetone collodion remover is available but less effective than acetone. EC2 paste can be softened with warm water for 1-2 minutes before electrode removal. Electrodes used on non-intact skin or when large amounts of blood are present on scalp require high level disinfection or sterilization before reuse, either steam sterilization for 5-10 minutes or glutaraldehyde (Cidex) soak for 45 minutes.
2. Needle electrodes. Disposable single use electrodes reduce expense of cleaning and risk of accidental needle sticks during cleaning.
3. Subdermal wire electrodes. Single use disposable.
4. After electrode removal, the patient's hair and scalp should be cleaned thoroughly. The scalp should be inspected for signs of skin breakdown or infection, with notification of nursing and physician staff if present.
5. If CCEEG staff is not available in-hospital at all times, there should be a plan for electrode removal if needed (i.e. unexpected urgent neuroimaging), including storage of needed materials in a location bedside caregivers can access.

E. Quantitative EEG Techniques

1. We suggest that QEEG trends be incorporated into CCEEG clinical workflows. QEEG trends cannot be interpreted in isolation from raw EEG. Computer processing of digital EEG data can make CCEEG review less time-consuming, may reveal subtle changes in the EEG occurring over long periods of time that would be missed on visual review of raw data (Scheuer and Wilson 2004), and can produce alerts or alarms to notify staff about changes in EEG patterns. Most quantitative EEG techniques for CCEEG involve calculation of fast Fourier transforms of EEG data into frequency and power measurements, with display over a compressed time scale (hours). Other techniques display rhythmicity, amplitude, or symmetry measures. A variety of graphical displays can be utilized to improve non-electroencephalographer interpretation of CCEEG (Claassen, Hirsch et al. 2004, Stewart, Otsubo et al. 2010, Zhang, Xanthopoulos et al. 2010, Schmidt and Claassen 2011, Foreman and Claassen 2012, Pensirikul, Beslow et al. 2013). Trends can help in assessment of sleep-wake cycles, recognition of slow changes in EEG activity over time, and identification of specific regions of interest for more detailed review.
2. This consensus statement does not describe all of the QEEG trends which have been used in CCEEG. Density spectral array (DSA) is a graphical picture of the EEG which compresses hours of activity into time, distribution of frequency, and power measurements. Other graphical displays include color spectrograms (power in each frequency band vs. time), total power in certain frequency bands, ratios of

power in certain bands over a broader spectrum of EEG power, envelope trends, amplitude-integrated EEG, and spectral edge displays. QEEG trends can be generated for individual EEG channels or combination of channels to provide overviews of homologous left and right brain regions.

3. When QEEG trends are utilized by non-EEG staff in the ICU to identify changes in brain activity, QEEG and raw EEG changes should be confirmed by expert EEG readers before changes in therapy are initiated. Review of quantitative displays sometimes quickly reveals important EEG changes such as seizures, but the technique is very susceptible to artifact. It is essential that the associated raw EEG be immediately available for review and comparison, to confirm that QEEG changes accurately reflect the ongoing EEG. A practical display is to utilize dual monitors, with one showing QEEG trends over 1 to several hours, and the second showing the raw CCEEG tracings at 10-20 seconds per page.
4. QEEG trends should include sufficient EEG channels for adequate spatial sampling of brain activity. As in limited montages for display of raw EEG, QEEG analysis of single or limited channels may miss seizures or events occurring in other brain regions. While such simplified trends may have some utility to identify shivering or monitor depth of sedation in general ICU patients, their sensitivity and specificity in patients with acute neurological injuries is largely unknown (Deogaonkar, Gupta et al. 2004, Seder, Fraser et al. 2010, Dou, Gao et al. 2014).
5. QEEG trends can aid in rapid identification and quantification of NCS, but may miss seizures, even when reviewed by experienced readers (Anderson and Wisneski 2008, Stewart, Otsubo et al. 2010, Sackellares, Shiau et al. 2011, Pensirikul, Beslow et al. 2013).
 - a. Many seizures in critically ill patients contain rhythmic waveforms in the 2-6 or 6-14 Hz frequency ranges. Seizures are often associated with transient increases in EEG power, and are easily recognized on graphical displays of total power in the 6-14Hz frequency band and in the color spectrogram (Williamson, Wahlster et al. 2014). Seizures shorter than 30 seconds may not be detected if 30 second windows are used for processing. Amplitude-integrated EEG can also be used for seizure identification. Many quantitative techniques can be obscured by any electrode or movement artifact. Use of the envelope trend, a graph of median amplitude in each 30 second epoch, is less susceptible to brief artifacts than graphs of total power. Some commercially available software includes proprietary trends (e.g. cerebral function monitor, CFM, rhythmicity spectrograms) which are also useful for seizure identification.
 - b. Current commercially available software allows nearly limitless variations in quantitative techniques, channels, and display methods. Different techniques may be helpful in different patients. Once an electrographic seizure is seen on EEG, quantitative trends can be fine-tuned to optimize identification (e.g. specific channels, more restricted frequency bands). Seizure monitoring trends should also include a trend for burst suppression ratio and interburst

intervals for monitoring of efficacy of cIV-ASDs such as midazolam, propofol and pentobarbital.

6. Because of the variety of techniques available, no definitive recommendations can be made regarding optimal QEEG trends for seizure identification. Some seizures are better seen on one type of trend than another. Use of several panels with different types of trends allows interpreters to choose among different views without requiring reprocessing of the data. Time windows for seizure detection trends should be 2 hours at most, and 30-60 minute windows are preferred.
7. QEEG trends can enhance identification of ischemia. Several quantitative EEG trends have been utilized to identify ischemia, but data are insufficient for strong recommendations. The most useful trends appear to be relative alpha variability (RAV, variability in the ratio of alpha power (6-14Hz) to total EEG power (1-20Hz)) (Vespa, Nuwer et al. 1997) and the post-stimulation alpha to delta ratio (ADR, ratio of alpha power (6-14Hz) to delta power (1-4Hz)) (Claassen, Hirsch et al. 2004). In retrospective analyses, both had excellent sensitivity (89-100%) but only moderate specificity. Channels should be selected to monitor specific vascular territories (e.g. F3-C3 for left anterior cerebral artery, C3-T3 for left middle cerebral artery). Longer time windows (4-12 hours) may aid in identification of slowly developing ischemia.
8. Seizure detection algorithms and automated background assessment. Most automated seizure detection algorithms were developed for ictal patterns seen in patients with established epilepsy, and have not been validated in ICU populations with acute symptomatic seizures (Sackellares, Shiao et al. 2011). Automated analysis of background patterns (e.g. burst-suppression, periodic patterns) are active research areas, but are not in routine clinical use (Cloostermans, de Vos et al. 2011, Westover, Ching et al. 2013, Shibasaki, Nakamura et al. 2014).

F. EEG and Behavioral Monitoring by Non-Physician Personnel

1. Patients undergoing CCEEG monitoring should be observed for key clinical events, such as movements or autonomic changes suggestive of seizures, changes in level of consciousness, potential sources of artifact, and administration of medications and sedation. In addition, EEG should be reviewed as often as logistically and technically feasible (at least twice daily) for data quality and important EEG changes. Behavioral and EEG observation can be performed at the bedside or centrally via hospital networks, and by a variety of ICU and EEG staff. Several possible models of EEG and behavioral monitoring are described below.
2. Bedside ICU staff can document some key clinical events, but are not likely to be continuously observing the patient. ICU staff should be trained to: a) maintain a record of patient behavior, clinical events, and sedative or antiseizure medication administration in nursing notes, a bedside log, or directly in the EEG recording; b) use the event button to indicate suspected seizures; c) perform tests of reactivity and annotate the EEG record when performed; and d) notify EEG staff when important clinical changes occur.

3. Video recording (bedside or remote) provides continuous assessment of patient behavior and activities around the patient bedside.
4. Raw EEG tracings (bedside or remote). Review of raw EEG is the most reliable way of identifying seizures and other important changes in EEG patterns. However, review of raw CCEEG poses several logistical problems: a) highly trained staff are required to continuously view the EEG; b) staff can only review a limited number of CCEEGs simultaneously (especially if also observing video streams); and c) networking and display equipment can be expensive.
5. QEEG graphical displays can be used both bedside and remotely to alert ICU staff of important changes in the EEG. These allow review of longer segments of EEG, decreasing the need for second-by-second attention to the EEG tracing.
6. Central continuous monitoring. This is the optimal means of correlating behavior with EEG features, assessing possible sources of artifact, and identifying acute changes in EEG features suggestive of neurologic deterioration. Although some CCEEG centers can perform many aspects of central continuous monitoring, the majority of centers cannot currently provide this level of real time review.
 - a. Patient behavior and activities around the patient beside are recorded continuously on video and audio time synchronized to EEG.
 - b. Events and automated event detection: Events of interest by patient or observer pushbutton or automated computer analysis of EEG (spike and seizure detection, quantitative EEG trends) generate “alerts” (audio, pager, and email) for bedside ICU staff and EEG staff.
 - c. Raw EEG may be continuously viewable.
 - d. Graphical displays of quantitative EEG can be incorporated into monitoring. These can include both trends over time and other processed data such as “bad electrode” displays.
 - e. Real-time assessment of EEG and video data optimizes the likelihood of early identification of EEG changes, and annotations may improve the efficiency of physician review and reporting. This system requires specialized equipment for recording and display of video, EEG, and quantitative EEG, and is therefore expensive.
 - f. Types of observation
 - 1) EEG review. EEG should be reviewed intermittently or continuously. The raw EEG traces are reviewed, typically with simultaneous video and often supplemented by quantitative EEG trends. Experienced NDTs are specially trained to identify clinical changes, EEG patterns, and QEEG patterns that may indicate seizures and other neurologic events. NDTs frequently or continuously review EEG, video, and quantitative EEG trends, annotate the recording, highlight segments for later physician review, and notify physician electroencephalographers when

significant changes in EEG occur. Use of NDTs as observers requires adjustment in staffing patterns for EEG laboratories (weekend and night shifts). Optimally, at least one NDT should be assigned to EEG monitoring exclusive of all other duties, so that recordings are truly monitored continuously. If large numbers of patients are monitored, additional staff may be needed. A practical ratio of 1 NDT to 4-8 patients is suggested, although there is no data on the optimal technologist to patient ratio. Use of NDTs limits the number of potential false positive reports to physicians interpreting EEGs.

- 2) Video and QEEG trend review. Specially trained patient observers can identify clinical events on video, and can also be trained to recognize changes in quantitative EEG, but are not expert in EEG pattern recognition and cannot substitute for NDTs. Electroencephalographers would need to review all EEG tracings before clinical recommendations are made, and use of staff who are less familiar with EEG may result in large numbers of false positive notifications.
7. Remote monitoring (out-of-hospital). Technological advances now allow review of on-going EEG recordings from remote locations, although remote real-time video review is still difficult. CCEEG requires a team approach, specific expertise, and a high level of communication between EEG and ICU personnel. Remote access and monitoring employing qualified personnel as described in Section IV might be used to supplement an hospital-based CCEEG team, but does not in itself satisfy all recommendations for CCEEG.

G. Review, Interpretation and Reports

1. There are widely variable practices for review and reporting of CCEEG, depending on local resources (Abend, Dlugos et al. 2010). Several options are described below. Each CCEEG program should develop and follow written policies and procedures for CCEEG review and reporting, adapted for local availability of equipment and staff. Remote access to the EEG tracings facilitates timely interpretation.
2. CCEEG should be reviewed frequently by trained NDTs for technical quality and by electroencephalographers for important events, at a minimum twice daily. The first 30 to 60 minutes of EEG recording should be reviewed and interpreted as soon as possible, with results conveyed to the clinical care team. In some centers, this initial review is performed by neurology trainees, ICU physicians with training in EEG, clinical neurophysiology trainees, or attending EEG staff. In other centers, NDTs summarize and annotate the EEG record, which is reviewed by attending EEG staff. In all cases, the responsible attending EEG physician should be available for confirmation of any important EEG findings noted by other reviewers. More frequent review should be performed as indicated by the CCEEG findings, the patient's clinical status, and the occurrence of any clinical events.

3. Daily reports should be generated by physician electroencephalographers to allow timely clinical correlation of the CCEEG findings. Written reports should be written at least daily, and should clearly describe any EEG, QEEG, and video events. Interim written or verbal reports should be issued to the clinical care team when important changes occur. Reports generally include: a) patient identifying information; b) recording techniques used; c) reason for monitoring and patient history; d) interim clinical changes for multi-day studies, e) relevant medications, including dose and duration of any ASDs, f) duration of monitoring; g) description of background EEG patterns, including presence or absence of periodic and rhythmic patterns and presence or absence of reactivity; h) interpretation of clinical and/or EEG events (e.g. seizures) individually or collectively; i) description of quantitative EEG trends if used; j) overall impression or summary of findings; and k) clinical correlation. A wide variety of patterns can be seen in CCEEG studies; use of standardized terminology for EEG reports may improve inter-reader agreement (Hirsch, LaRoche et al. 2013, Gaspard, Hirsch et al. 2014).
4. Communication with the clinical team. In order to provide the most useful interpretation to the clinical team, it is helpful to have daily updates of the patient's clinical status, including level of alertness, medications initiated or discontinued, interim procedures, and results of testing such as CT, MRI, and Transcranial Doppler imaging. Computerized medical records can be reviewed if available. Alternatively, nurses and physicians can enter information into the EEG machine itself. Results of CCEEG should be transmitted to the clinical care team as soon as available. In addition to written reports, this often involves phone discussions or multidisciplinary team rounds, which should be documented in the patient's medical record.
5. CCEEG electroencephalographers should consider utilizing a database to track the utilization and utility of CCEEG in their own institution. CCEEG is an expensive and labor-intensive procedure, with rapidly evolving indications and technical specifications. Tracking the number and duration of studies, indications and diagnoses, and proportions of studies showing seizures or other clinically important findings allows centers to modify their practice to meet local needs.

H. CCEEG Data Storage Protocols

1. Storage for initial analysis. All video/audio data and EEG data should be saved until appropriately analyzed and reported by trained personnel. After CCEEG review, data can be reduced by: a) selection of pertinent video segments (clinical and EEG events), and then deletion of all other video but retention of entire EEG, or b) selection of pertinent video and EEG segments (baseline background, clinical and EEG events), and then deletion of the remainder of EEG and video data. The first option may be more appropriate when quantitative EEG trends are utilized, and also minimizes the amount of time that NDTs spend annotating and clipping data. Edited data to be stored should include a short period (approximately 2 min) prior to and after any events, as well as the entire episode. A log of the contents of all edited data should be maintained, preferably as part of the detailed report. If

QEEG trends are used for interpretation, these trends should be stored with the EEG study as they were viewed during interpretation.

2. Archival storage. Video and EEG data can be archived to digital media, including DVDs, external hard drives, archive servers, and network attached storage devices. Each CCEEG monitoring center should consult their institutional and/or state guidelines for the mandated duration of data storage. Legal counsel may be required if established guidelines are lacking. In most instances, EEG recordings should be stored for 7 years or until pediatric patients reach 18 years of age, whichever is longer.
3. Data formats and transmission. Ideally, EEG data should be able to be recorded and stored in nonproprietary or publicly available formats to ensure that data can be viewed outside the manufacturer's proprietary software (Society 2008). For practical reasons, most EEG is recorded and stored in a proprietary format, with conversion to open formats only if needed.

VIII. CONCLUSION

CCEEG is an emerging technique to identify secondary brain injuries such as seizures and ischemia in critically ill patients. CCEEG is distinct from video-EEG monitoring for epilepsy, in terms of both equipment and personnel, and requires specialized training and protocols. While the current standard in most centers is continuous recording with intermittent review and interpretation, advances in technology are facilitating real-time review. Optimal performance of CCEEG requires a collaborative team approach between CCEEG staff and bedside ICU caregivers, with frequent communication regarding changes in clinical status and in EEG.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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