American Clinical Neurophysiology Society

DRAFT: Consensus Statement: Indications, Technical Specifications and Clinical Practice of Continuous EEG Monitoring of Critically Ill Adults and Children

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I. INTRODUCTION AND PURPOSE

Critically ill patients are at high risk for a variety of neurologic insults, including seizures, ischemia, edema, infection, and increased intracranial pressure, which can result in permanent neurologic disability if untreated. Despite these risks, there are few techniques for continuously monitoring brain function. Electroencephalography (EEG) measures brain electrical activity, can be recorded continuously at the bedside, has good spatial and excellent temporal resolution, and is sensitive to changes in both brain structure and function (Nuwer 1994). Over the past decade, technical advances have improved the efficiency of continuous EEG (CEEG) recording and remote review, leading to a greater than four-fold increase in the number of CEEGs performed in intensive care units (ICUs) (Ney, van der Goes et al. 2013). Recent surveys, however, show substantial variability in why and how CEEG is performed in the ICU (Abend, Dlugos et al. 2010, Sanchez, Arndt et al. 2013, Gavvala, Abend et al. In press.), highlighting the need for clinical guidance on this expensive and labor-intensive procedure.

Critical care continuous EEG (CCEEG) refers to the simultaneous recording of EEG and clinical behavior over extended time periods (hours to weeks) in critically ill patients at risk for neurologic deterioration. CCEEG typically includes simultaneous video recording, and often includes graphical displays of quantitative EEG trends. The goal of CCEEG is to identify changes in brain function (e.g. nonconvulsive seizures (NCS) or ischemia) which may not be evident by neurological examination alone, in order to facilitate early detection and management of these abnormalities.

This consensus statement applies only to critically ill adult and pediatric patients, not to long-term monitoring of awake and alert patients with epilepsy (LTME), sleep monitoring, or intraoperative monitoring. Separate recommendations have been developed for CEEG in critically ill neonates (Shellhaas, Chang et al. 2011).

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 below. 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 and cost constraints, CCEEG is typically acquired continuously and reviewed intermittently by neurodiagnostic

technologists (NDTs) for technical quality and changes in EEG patterns and 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 indications for monitoring, and the patient's clinical status. CCEEG indications and technical specifications will be updated as new data become available.

The American Clinical Neurophysiology Society's CCEEG Guidelines Committee describes a variety of models for CCEEG. Some techniques are available in only a few specialized centers and represent an "idealized" system for CCEEG. The committee recognizes that many CCEEG programs do not have full access to all equipment, technical staff, and interpreting staff described below, but should use these recommendations for program development and improvement. Each center should provide CCEEG at the highest level that local resources allow, and consider transferring patients to more specialized centers when local resources are insufficient for patient care needs.

CCEEG is often requested as an urgent or emergency study in critically ill patients. Current staffing models may not support 24-hour 7-day per week in-house NDTs. This consensus statement therefore addresses minimum techniques for CCEEG under emergency circumstances, as well as optimal techniques once qualified NDTs are available.

CCEEG is longer than routine EEG, but the required duration varies depending on the indications for monitoring and individual patient characteristics. **In most cases, recording for a minimum of 24 hours is recommended**, and longer recording is recommended for selected populations (see section II. Indications). To optimally identify neurological deterioration in critically ill patients, CCEEG should be started as soon as feasible in selected patient groups with acute brain injuries, altered mental status, or risk for brain ischemia (see section II. Indications). Subsequent CCEEG recordings can then be compared to this initial "baseline" recording to identify secondary neurological insults.

The second section of this consensus statement lists the most common indications for CCEEG in adults and children. The next sections cover technical aspects of CCEEG, such as qualifications of personnel performing and interpreting CCEEG, equipment, documentation, and safety. The final sections address commonly used techniques for specific indications in adults and children.

II. INDICATIONS FOR CCEEG

CCEEG should be considered for the following commonly accepted indications (Claassen, Taccone et al. 2013)***.***

A. Diagnosis of Nonconvulsive Seizures (NCS) and Nonconvulsive Status Epilepticus (NCSE)

1. ***CCEEG should be initiated for critically ill patients in any of the following scenarios***:
   a. ***Persistently abnormal mental status following generalized convulsive status epilepticus (GCSE) or other clinically-evident***

seizures. After apparently successful treatment of GCSE, many patients remain comatose, obtunded, or confused (Treiman, Meyers et al. 1998). During 24 hours of CCEEG after GCSE, NCS were recorded in 48% and NCSE in 14% (DeLorenzo, Waterhouse et al. 1998). Similarly, NCS were seen in 43% of patients who had convulsive seizures before monitoring (Claassen, Mayer et al. 2004). Children with convulsive seizures (McCoy, Sharma et al. 2011, Greiner, Holland et al. 2012, Abend, Arndt et al. 2013) or GCSE (Williams, Jarrar et al. 2011) prior to CCEEG are at higher risk for NCS. Thirty-three percent of 98 children undergoing CCEEG after GCSE terminated had ongoing electrographic seizures (Sanchez Fernandez, Abend et al. 2014). Impaired consciousness after clinical seizures end can be secondary to prolonged postictal effects, sedative effects of antiseizure drugs, or continued NCS. If a patient is not showing clear signs of improvement alertness within 10 minutes, or still has any impairment of consciousness for more than 30 minutes after cessation of motor or other clinically-evident seizure activity, EEG should be performed to assess for ongoing seizure activity(Brophy, Bell et al. 2012, Claassen, Taccone et al. 2013).

b. ***Acute supratentorial brain injury with altered mental status.,*** Table 1 lists types of acute brain injuries in which NCS are commonly seen, including CCEEG traumatic brain injury (TBI), subarachnoid hemorrhage (SAH), intracerebral hemorrhage (ICH), encephalitis, acute ischemic stroke, and during and after therapeutic hypothermia post cardiac arrest (Claassen, Taccone et al. 2013).
c. ***Fluctuating mental status or unexplained alteration of mental status without acute brain injury.*** Mental status abnormalities can include agitation, lethargy, fixed or fluctuating neurologic deficits such as aphasia or neglect, obtundation, and coma. NCS have been reported in 8-10% of patients with unexplained coma or altered consciousness who did not have prior clinical seizures (Towne, Waterhouse et al. 2000, Oddo, Carrera et al. 2009, Kurtz, Gaspard et al. 2014).
d. ***Identification of generalized periodic discharges (GPDs) or lateralized periodic discharges (LPDs) on routine or emergent EEG***. Adults and children with generalized or lateralized periodic discharges are more likely to develop NCS or NCSE (Jette, Claassen et al. 2006, Foreman, Claassen et al. 2012, Ong, Gilmore et al. 2012, Akman, Abou Khaled et al. 2013, Gaspard, Manganas et al. 2013, Pedersen, Rasmussen et al. 2013). The presence of lateralized rhythmic delta activity (LRDA) appears to have the same high association with seizures as LPDs and is also a reasonable indication for CCEEG (Gaspard, Manganas et al. 2013).
e. ***Patients who are pharmacologically paralyzed (e.g. therapeutic hypothermia protocols, extracorporeal membrane oxygenation (ECMO)) and are at risk for seizures***. Paralytic agents will prevent any clinical manifestations of seizures, making CCEEG recording essential to identify seizures in high risk patients.

2. Evidence supporting utility of CCEEG in critically ill patients. Evaluation for suspected NCS is the most common indication for CCEEG (Abend, Dlugos et al. 2010, Sanchez, Carpenter et al. 2013). NCS, also called subclinical, electrographic-only, subtle, occult, or silent seizures, have minimal or no overt clinical signs and can only be reliably diagnosed using EEG. NCSE, in which NCS are prolonged or repetitive, is variably defined as NCS lasting more than 30 minutes or recurrent over 30 minutes without return to normal consciousness; continuous or recurrent NCS lasting more than 5 minutes (Brophy, Bell et al. 2012), and continuous or recurrent NCS for more than 50% of an EEG epoch.
    a. NCS occur in 8-48% of critically ill adults (Privitera, Hoffman et al. 1994, Jordan 1995, DeLorenzo, Waterhouse et al. 1998, Vespa, Nenov et al. 1999, Towne, Waterhouse et al. 2000, Claassen, Mayer et al. 2004, Pandian, Cascino et al. 2004, Oddo, Carrera et al. 2009) and 6-47% of children with altered mental status(Hosain, Solomon et al. 2005, Jette, Claassen et al. 2006, Tay, Hirsch et al. 2006, Abend and Dlugos 2007, Abend, Topjian et al. 2009, Shahwan, Bailey et al. 2010, Abend, Gutierrez-Colina et al. 2011, McCoy, Sharma et al. 2011, Williams, Jarrar et al. 2011, Greiner, Holland et al. 2012, Kirkham, Wade et al. 2012, Schreiber, Zelleke et al. 2012, Abend, Arndt et al. 2013, Arndt, Lerner et al. 2013, Hasbani, Topjian et al. 2013).

Table 1: Common neurological, medical, and surgical conditions associated with high likelihood of recording seizures on CCEEG

	Adults	Children	References
Post convulsive status epilepticus	48%	26-57%	(DeLorenzo, Waterhouse et al. 1998, Tay, Hirsch et al. 2006, Abend, Gutierrez-Colina et al. 2011, Williams, Jarrar et al. 2011, Abend, Wusthoff et al. 2013, Sanchez Fernandez, Abend et al. 2014)
Aneurysmal subarachnoid hemorrhage	Any seizure: 11-19% NCSE: 3-13%		(Dennis, Claassen et al. 2002, Claassen, Mayer et al. 2004, Little, Kerrigan et al. 2007, Claassen, Albers et al. 2014, Westover, Shafi et al. 2014)
Intraparenchymal hemorrhage	16-23%	11-100%	(Vespa, O'Phelan et al. 2003, Jette, Claassen et al. 2006, Saengpattrachai, Sharma et al. 2006, Tay, Hirsch et al. 2006, Claassen, Jette et al. 2007, McCoy, Sharma et al. 2011, Greiner, Holland et al. 2012, Kirkham, Wade et al. 2012, Kurtz, Gaspard et al. 2014, Payne, Zhao

			et al. 2014, Westover, Shafi et al. 2014)
Moderate to severe traumatic brain injury	18-33%	14-70%	(Vespa, Nuwer et al. 1999, Claassen, Mayer et al. 2004, Jette, Claassen et al. 2006, Ronne-Engstrom and Winkler 2006, Abend, Gutierrez-Colina et al. 2011, Williams, Jarrar et al. 2011, Schreiber, Zelleke et al. 2012, Abend, Arndt et al. 2013, Arndt, Lerner et al. 2013, Hasbani, Topjian et al. 2013, Sanchez, Arndt et al. 2013, Payne, Zhao et al. 2014)
Central nervous system infections	10-33%	16-100%	(Claassen, Mayer et al. 2004, Jette, Claassen et al. 2006, Saengpattrachai, Sharma et al. 2006, Tay, Hirsch et al. 2006, Carrera, Claassen et al. 2008, Abend, Gutierrez-Colina et al. 2011, Williams, Jarrar et al. 2011, Gwer, Idro et al. 2012, Schreiber, Zelleke et al. 2012, Abend, Arndt et al. 2013, Payne, Zhao et al. 2014, Westover, Shafi et al. 2014)
Recent neurosurgical procedures	23%	71%	(Claassen, Mayer et al. 2004, Payne, Zhao et al. 2014, Westover, Shafi et al. 2014)
Brain tumors	Any seizure: 23-37% NCSE: 9-12%	19-66%	(Jette, Claassen et al. 2006, Abend, Gutierrez-Colina et al. 2011, Greiner, Holland et al. 2012, Kirkham, Wade et al. 2012, Abend, Arndt et al. 2013, Marcuse, Lancman et al. 2014, Westover, Shafi et al. 2014)
Acute ischemic stroke	6-27%	20-71%	(Vespa, O'Phelan et al. 2003, Claassen, Mayer et al. 2004, Jette, Claassen et al. 2006, Saengpattrachai, Sharma et al. 2006, Abend, Gutierrez-Colina et al. 2011, McCoy, Sharma et al. 2011, Greiner, Holland et al. 2012, Kirkham, Wade et al. 2012, Sanchez, Carpenter et al. 2013, Kurtz, Gaspard et al. 2014, Payne, Zhao et al. 2014,

			Westover, Shafi et al. 2014)
Hypoxic-ischemic injury following cardiac or respiratory arrest	10-59%	16-79%	(Claassen, Mayer et al. 2004, Jette, Claassen et al. 2006, Tay, Hirsch et al. 2006, Abend, Topjian et al. 2009, Abend, Gutierrez-Colina et al. 2011, Kawai, Thapalia et al. 2011, Williams, Jarrar et al. 2011, Rittenberger, Popescu et al. 2012, Abend, Arndt et al. 2013, Crepeau, Rabinstein et al. 2013, Knight, Hart et al. 2013, Legriel, Hilly-Ginoux et al. 2013, Sanchez, Arndt et al. 2013, Payne, Zhao et al. 2014, Sadaka, Doerr et al. 2014, Westover, Shafi et al. 2014)
Sepsis-associated encephalopathy	32%	58%	(Oddo, Carrera et al. 2009, Abend, Arndt et al. 2013)
Extracorporeal membrane oxygenation (ECMO)		21%	(Piantino, Wainwright et al. 2013)
Epilepsy Related	33-39%	11-71%	(Claassen, Mayer et al. 2004, Jette, Claassen et al. 2006, Saengpattrachai, Sharma et al. 2006, Tay, Hirsch et al. 2006, Hyllienmark and Amark 2007, Abend, Gutierrez-Colina et al. 2011, McCoy, Sharma et al. 2011, Abend, Arndt et al. 2013, Westover, Shafi et al. 2014) Hyllienmark 2007 McCoy 2011

b. NCS are associated with other signs of neurologic injury, such as increased intracranial pressure, increased edema and mass effect, changes in tissue oxygenation, and local increases in lactate, lactate/pyruvate ratio, and glutamate, suggesting that NCS play a role in secondary brain injury (Vespa, Prins et al. 1998, Vespa, Nuwer et al. 1999, Vespa, Martin et al. 2002, Vespa, O'Phelan et al. 2003, Vespa, Miller et al. 2007, Fabricius, Fuhr et al. 2008, Hartings, Watanabe et al. 2011, Dreier, Major et al. 2012).
c. Patients less than 18 years of age may be at higher risk than adults for NCS and NCSE (Claassen, Mayer et al. 2004), and within the pediatrics age group, neonates and infants may be at particularly high risk (Hosain, Solomon et al. 2005, Jette, Claassen et al. 2006, Saengpattrachai, Sharma et al. 2006, Tay, Hirsch et al. 2006, Abend and Dlugos 2007,

Abend, Topjian et al. 2009, Shahwan, Bailey et al. 2010, Abend, Gutierrez-Colina et al. 2011, McCoy, Sharma et al. 2011, Williams, Jarrar et al. 2011, Greiner, Holland et al. 2012, Kirkham, Wade et al. 2012, Schreiber, Zelleke et al. 2012, Abend, Arndt et al. 2013, Arndt, Lerner et al. 2013, Hasbani, Topjian et al. 2013).

d. Prolonged NCS or NCSE are associated with increased mortality and increased risk for poor neurologic outcome (Young, Jordan et al. 1996, Abend, Arndt et al. 2013, Topjian, Gutierrez-Colina et al. 2013), so rapid diagnosis is encouraged. Seventy-nine percent of physicians responding to a survey of CCEEG practice responded that CCEEG should be initiated immediately if NCS or NCSE are suspected (Abend, Dlugos et al. 2010).
e. The use of CCEEG in ICU patients at risk for NCS leads to changes in treatment in the majority of both adults (Kilbride, Costello et al. 2009) and children (Abend, Topjian et al. 2011).

3. ***When CCEEG is performed for identification of seizures, concurrent video recording is strongly recommended.*** Careful review of video can sometimes identify subtle clinical seizure manifestations which may not have been detected by bedside staff.
4. The impact of NCS identification and management on outcome has not yet been established, and may differ based on the NCS etiology, duration, and management approach. Timing of initiation of CCEEG for NCS identification. Because prolonged NCSE is associated with higher morbidity and mortality and treatment is likely to be effective earlier in the course of NCSE, ***CCEEG should be initiated as soon as possible when NCSE is suspected***. If feasible, initiation within one hour is recommended (Brophy, Bell et al. 2012).
5. ***When CCEEG is performed for identification of seizures, CCEEG should be reviewed by CCEEG personnel at least twice daily.*** If frequent NCS or NCSE is identified, more frequent interpretation should be provided until seizures are controlled.
6. Duration of CCEEG for NCS identification. ***To evaluate for NCS, CCEEG should be recorded for at least 24 hours.*** Typical 30-60 minute EEG recordings have low sensitivity for NCS (45-56%) (Claassen, Mayer et al. 2004, Pandian, Cascino et al. 2004, Abend, Gutierrez-Colina et al. 2011). About 80-95% of patients with NCS can be detected within 24-48 hours (Claassen, Mayer et al. 2004, Jette, Claassen et al. 2006, Abend and Dlugos 2007, Shahwan, Bailey et al. 2010, Abend, Gutierrez-Colina et al. 2011). Most seizures in non-comatose patients occur within the first 24 hours, while an additional 24 hours may be required in comatose patients (Claassen, Mayer et al. 2004). All of these studies were based on clinically indicated monitoring and none monitored all patients for the entire duration of critical illness. Thus, there may be some patients in whom NCS started after monitoring is discontinued. In specific populations, such as patients who are comatose, have periodic discharges, or are pharmacologically sedated, NCS may occur later, so more prolonged monitoring (48 hours or more) may be needed (Claassen, Mayer et al. 2004, Abend, Topjian et al. 2009). Brief (30 minute) serial EEGs have been demonstrated to have similar yield to CCEEG in post

cardiac arrest patients undergoing hypothermia (Crepeau, Fugate et al. 2014). Additional studies are needed to confirm the utility and cost effectiveness of CCEEG versus serial briefer EEG in other populations.

B. <u>Assessment of Efficacy of Therapy for Seizures and Status Epilepticus</u>

1. ***Once NCS have been diagnosed, CCEEG is required to confirm that seizures have stopped with antiseizure treatment.***
   a. Duration of CCEEG for therapy assessment: ***CCEEG should be recorded until seizures have been controlled for at least 24 hours. Recurrence of altered consciousness in a patient with known NCS should prompt consideration of repeat CCEEG to exclude recurrent seizures.***
2. ***For patients with refractory status epilepticus (RSE), CCEEG should be used to monitor the efficacy of continuous intravenous antiseizure drugs (cIV-ASDs)*** such as midazolam, propofol, or pentobarbital, for either seizure suppression or EEG suppression.
   a. RSE is defined as clinical or electrographic seizures which continue after initial treatment for SE, typically with a benzodiazepine and at least one other acceptable antiseizure drug (Brophy, Bell et al. 2012).
   b. CCEEG can confirm cessation and absence of recurrence of seizures. Most seizures during treatment with IV-ASDs are subclinical and would not be detected without CCEEG (Claassen, Hirsch et al. 2001, Claassen, Hirsch et al. 2002). CCEEG can also be used to monitor the adequacy of burst-suppression (duration of burst and interburst periods) or complete EEG suppression induced by cIV-ASDs (Krishnamurthy and Drislane 1999, Jordan and Hirsch 2006, Prins, de Hoog et al. 2007, Rossetti, Milligan et al. 2011).
3. ***When CCEEG is performed to assess response to treatment, concurrent video recording is strongly recommended.*** In addition to recording subtle clinical manifestations, video recording can help to document the response to treatment, such as improvement in mental status following administration of antiseizure drugs.
4. ***When CCEEG is performed for monitoring treatment, CCEEG should be reviewed by CCEEG personnel at least twice daily.*** If frequent NCS or NCSE is identified, more frequent interpretation should be provided until seizures are controlled.
5. Duration of CEEG for RSE: ***CCEEG should be recorded during the entire period that cIV-ASDs are utilized.*** Seizures may recur despite EEG-confirmed burst-suppression or complete suppression (Claassen, Hirsch et al. 2001, Claassen, Hirsch et al. 2002), so intermittent monitoring for burst-suppression alone is insufficient to confirm complete seizure control. ***Because there is a high risk of seizure recurrence after withdrawal of cIV-ASDs, CCEEG generally should be continued for at least 24 hours after cIV-ASDs are withdrawn*** (Abend, Dlugos et al. 2010). For cIV-ASDs with long half-lives, more prolonged recording may be necessary, but the required duration of monitoring has not been standardized.

C. Differential Diagnosis of Clinical Paroxysmal Events

1. ***CCEEG is recommended to evaluate clinical paroxysmal events suspected to be seizures to help determine if they are epileptic or nonepileptic.***
    a. Critically ill adults and children may have a variety of episodic abnormal movements or other clinical events which raise concern for epileptic seizures (Benbadis, Chen et al. 2010, Boesebeck, Freermann et al. 2010, Williams, Jarrar et al. 2011). Antiseizure drugs (ASDs) may be initiated for these events, but carry a risk for sedation, hypersensitivity reactions, and other adverse effects including cardiac and respiratory dysfunction. Exclusion of seizures may prevent initiation of or facilitate withdrawal of unnecessary ASDs.
    b. Episodic events which may benefit from evaluation with video CCEEG include: 1) Motor movements such as subtle face or limb twitching, nystagmus, gaze deviation, eyelid fluttering, chewing, myoclonus, tremors, rigors, episodic posturing and other paroxysmal or repetitive limb or trunk movements; 2) paroxysmal autonomic spells such as unexplained apnea, tachycardia, flushing, or blood pressure changes; or 3) unexplained paroxysmal increases in intracranial pressure or lactate or lactate/pyruvate ratio on microdialysis. EEG may not detect seizures with a small field or deep location. Because only approximately 21% of simple partial seizures show changes on scalp EEG (Devinsky, Kelley et al. 1988), a normal EEG during a clinical event does not exclude an epileptic origin. Intracranial EEG recordings of critically ill patients show many seizures that are not detected on the scalp EEG (Waziri, Claassen et al. 2009, Claassen, Perotte et al. 2013). Although these typically have no clinical manifestations, seizures seen only on intracranial EEG were associated with systemic effects including increases in blood pressure and heart rate (Claassen, Perotte et al. 2013).
2. ***When CCEEG is performed for differential diagnosis, review by CCEEG personnel should be performed at least twice daily, and as soon as possible after an important clinical event is identified.***
3. Duration of CCEEG for differential diagnosis: ***If local resources allow, CCEEG should be continued until several typical clinical events of interest have been recorded, or until the patient's clinical status improves and the question of possible seizures is no longer relevant.*** A minimum of 24 hours of CCEEG is usually required to evaluate for NCS.

D. Detection of Cerebral Ischemia

1. ***CCEEG can be used to detect ischemia in ICU patients at high risk for ischemia.*** During ischemia, EEG shows a progressive sequence of changes involving loss of fast activity followed by increasing slow activity (Jordan 2004). CCEEG, and particularly quantitative EEG trends, can be used to detect changes in cortical perfusion before irreversible infarct occurs (Vespa, Nuwer et al. 1997, Claassen, Hirsch et al. 2004).

a. EEG and quantitative EEG techniques have been used to identify ischemia during neurosurgical and interventional neuroradiology vascular procedures (Plestis, Loubser et al. 1997, Laman, van der Reijden et al. 2001, Pinkerton 2002, van Putten, Peters et al. 2004, Botes, Le Roux et al. 2007, Ballotta, Saladini et al. 2010, Mishra, Banday et al. 2011, Skordilis, Rich et al. 2011).
b. Retrospective studies have shown that CCEEG and quantitative trends can identify delayed cerebral ischemia (DCI) during vasospasm after SAH, but no prospective studies have been performed (Vespa, Nuwer et al. 1997, Claassen, Hirsch et al. 2004). Most centers using CCEEG for identification of vasospasm monitor patients at highest risk (severe SAH with Hunt and Hess grades 3-5 or large amounts of cisternal blood, Fisher grade 3). Because EEG is nonspecific as to etiology of changes, CCEEG is typically used in conjunction with other ancillary testing (e.g. MR/CT perfusion or angiography, TCDs or conventional angiography) to identify DCI and may predict which patients are at risk for DCI earlier than other studies.
c. CCEEG holds promise for ischemia identification in patients with hemodynamic lesions and borderline flow or those at high risk for acute ischemic stroke (Sheorajpanday, Nagels et al. 2009), but at this time real-time identification of ischemia is usually not feasible as it requires continuous real-time analysis, ideally of the raw and quantitative EEG. This may change as resources increase and automated EEG analysis improves, and if intracranial EEG recordings are utilized more often.

2. ***When CCEEG is performed for ischemia identification, review by CCEEG personnel should be frequent enough to allow therapeutic intervention to prevent or reverse ischemic insults.*** The optimal frequency of review has not been determined and may vary for different indications. For vasospasm, in which ischemia typically develops over several hours, CCEEG should be reviewed at least three times daily, while for patients at risk for acute ischemic stroke, more frequent review may be necessary, especially while the patient is asleep.
3. ***Because it is difficult to detect changes from ischemia on raw EEG over prolonged time periods, CCEEG for ischemia should include quantitative EEG analysis,*** such as graphical displays of power ratios over time.
4. Duration of CCEEG for ischemia identification: ***CCEEG should be continued during the period of time when the patient is at highest risk for ischemia.***
    a. SAH. CCEEG should be started before the highest risk window for vasospasm begins (approximately day 3 post SAH), to establish a baseline recording. Ideally, this should be as soon as the aneurysm is secured. CCEEG should be continued until the window for vasospasm has passed (day 14) or the patient is clinically felt to no longer be at risk for vasospasm.
    b. The optimal duration of monitoring for ischemia in other patient groups has

not been established, and should be individualized for the specific clinical situation. A practical guide would be to continue CCEEG during the highest-risk window for ischemia (e.g. 24-48 hours in a patient with crescendo transient ischemic attack (TIA) or 24 hours following carotid endarterectomy).

E. Monitoring of Sedation and High-Dose Suppressive Therapy

1. CCEEG can be used in conjunction with the clinical examination to assess level of consciousness in patients requiring intravenous sedation or pharmacologically-induced coma (Walder, Suter et al. 2001, Ypparila, Korhonen et al. 2002, de Wit and Epstein 2003, Doenicke, Kugler et al. 2007, Mirski and Hemstreet 2007). Once a patient is unresponsive, it can be very difficult to judge the degree of sedation on clinical grounds alone. The goal is to optimize EEG suppression while avoiding oversedation and hemodynamic complications, but no studies have addressed this indication. Although some quantitative EEG methods have been utilized for monitoring analgesia and sedation in the ICU (Sessler, Jo Grap et al. 2008), these methods have not been validated in patients with neurologic dysfunction.
2. The most common use is monitoring burst-suppression induced by pentobarbital in patients with increased intracerebral pressure (Hyllienmark and Amark 2007) or refractory status epilepticus (see II.B.2.b).
3. When CCEEG is performed for monitoring sedation, CCEEG should be reviewed by CCEEG personnel at least twice daily, and as requested by the clinical care team.
4. Duration of CCEEG for monitoring sedation: The optimal duration of monitoring for this indication has not been established, and should be individualized for the specific clinical situation.

F. Assessment of Severity of Encephalopathy and Prognostication

1. Several grading systems have been developed to describe the severity of EEG abnormalities and aid in prognosis (Synek 1990, Young, Wang et al. 2004). The grade or degree of abnormality correlates fairly well with the level of consciousness, although EEG changes may precede or lag clinical changes. Serial or continuous studies may therefore be helpful when following disease evolution.
2. EEG can help to predict outcome in several neurologic conditions, although it is unclear whether prolonged monitoring is superior to briefer EEG recordings performed at specific times after brain injury. In addition, most EEG parameters used to predict good outcome have a fairly high false positive rate (i.e. EEG shows favorable pattern, but patient still has poor clinical outcome). Unfavorable prognostic factors include isoelectric pattern, burst suppression pattern, periodic patterns and electrographic seizures (Synek 1988, Synek 1990, Young, Kreeft et al. 1999, Young, Wang et al. 2004). Favorable prognostic features include background continuity, spontaneous variability, reactivity to stimulation, and presence of normal sleep patterns (Synek 1988, Synek 1990, Young, Kreeft et al. 1999, Young, Wang et al. 2004).

3. Clinical populations in which EEG may aid in prognosis include: 1) severe traumatic brain injury, including non-accidental traumatic brain injury in infants (Vespa, Nuwer et al. 1999, Vespa, Boscardin et al. 2002, Stevens and Sutter 2013); 2) hypoxic ischemic encephalopathy following cardiac arrest (without or with therapeutic hypothermia) (Kessler, Topjian et al. 2011, Sandroni, Cavallaro et al. 2013a, Sandroni, Cavallaro et al. 2013b) (Rossetti, Oddo et al. 2010); and 3) SAH (Claassen, Hirsch et al. 2006).
4. When CCEEG is performed for prognostication, CCEEG should be reviewed by CCEEG personnel at least twice daily, and as requested by the clinical care team.
5. Duration of CCEEG for prognosis: The optimal duration of monitoring for this indication has not been established, and should be individualized for the specific clinical situation. At this time, CCEEG has not been demonstrated to be of greater utility than standard EEG at specified time points (Rossetti, Oddo et al. 2010).

III. 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 neurophysiology and specifically in CCEEG.***
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. Training and/or certification in clinical neurophysiology and EEG
      1) Certification in Clinical Neurophysiology (e.g. American Board of Psychiatry and Neurology in the subspecialty of Clinical Neurophysiology or American Board of Clinical Neurophysiology), OR
      2) Completion of 1 year fellowship training in clinical neurophysiology with concentration in EEG (at least 9 months) and at least 3 months of CCEEG, OR
      3) For interpretation of CCEEG only (e.g. neurointensivists), at least 6 months post-residency full time training in CCEEG
   d. Special training 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
   e. Special training in the 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.

f. Special training in the use, yield and limitations of quantitative EEG graphical trending.

3. Responsibilities
   a. Development of policies and procedures related to CCEEG (medical director of CCEEG program)
   b. Analysis of pertinent segments of EEG and behavioral data reviewed in all 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. <u>CCEEG Neurodiagnostic Technologists (NDT)</u>

1. ***CCEEG should be performed by appropriately trained, certified, and supervised neurodiagnostic technologists.***
2. 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 CCEEG recording under the direct supervision of Neurodiagnostic Technology Specialist (NDTS I-II)
      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
3. Neurodiagnostic Technologist II (NDT II)
   a. Education / certification
      1) Meets ASET – The Neurodiagnostic Society National Competencies for Performing an Electroencephalogram
      2) Eligible for registration in EEG (Registered EEG Technologist, R. EEG T.) by ABRET Neurodiagnostic Certification and Accreditation
      3) Six months of NDT experience
   b. Responsibilities
      1) All responsibilities of NDT I
      2) Performs CCEEG recording under direct supervision of NDTS I-II
4. Neurodiagnostic Technologist III (NDT III)
   a. Education / certification
      1) Registration in EEG (Registered EEG Technologist, R. EEG T.) by ABRET
      2) Associate's degree in Electroneurodiagnostic Technology or

equivalent. Appropriate clinical experience may be substituted for this degree.

b. Responsibilities
   1) All responsibilities of NDT II
   2) Performs CCEEG recording independently

5. Neurodiagnostic Technology Specialist I ICU
   a. Education / certification
      1) Certification in Long Term Monitoring (CLTM) by ABRET
      2) Meets ASET National Competency Skill Standards for CCEEG Monitoring (2008)
      3) 3 years experience in NDT, including 1 year experience in CCEEG
         a) Special training in the use, routine maintenance, and troubleshooting of CCEEG equipment in the ICU, with particular emphasis on techniques for monitoring the integrity of data recording, electrical safety, and infection control.
         b) Special training and resultant expertise in the recognition of ictal and interictal electrographic patterns and in their differentiation from artifacts
         c) Special training and resultant expertise in quantitative EEG analysis and patterns suggestive of neurologic deterioration
         d) Special training and resultant expertise in the recognition of clinical seizures and seizure-related medical emergencies
         e) Successful completion of training in cardiopulmonary resuscitation
   b. Responsibilities
      1) All responsibilities of NDT III
      2) Technical operation and supervision of CCEEG studies (e.g., patient preparation, equipment set-up, and data recording)
      3) Review of quantitative EEG trends and selection of segments for later analysis, under the supervision of a physician
      4) Notification to physician electroencephalographer of changes in CCEEG activity which may reflect deterioration in brain function
6. Neurodiagnostic Technology Specialist II ICU
   a. Education / certification
      1) Registration in CLTM by ABRET
      2) Meets ASET National Competency Skill Standards for CCEEG Monitoring (2008)
      3) 3 years experience post CLTM credential
         a) Same special training as NDTS I ICU
   b. Responsibilities
      1) All responsibilities of NDTS I ICU
      2) Development of technical policies and procedures related to CCEEG in conjunction with electroencephalographer
      3) Supervision and training of CCEEG associated personnel, including NDTs, nurses, and other ICU staff
7. Neurodiagnostic Lab Assistant
   a. EEG Assistants perform some limited EEG tasks, typically during hours in

which NDTs are not available in the hospital. In some cases, EEG Assistants may be other medical personnel (e.g. patient care assistants, nurses, etc.) who have been trained in specific EEG tasks.

b. Education / certification
    1) Variable by center. At least high school diploma.
    2) If EEG Assistants are utilized, the center should have a written protocol 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

8. 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.
    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.

IV. 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 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 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 and may be limited by the presence of scalp wounds or other cranial monitoring devices.
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 2006a), with the following additional points for CCEEG.
2. Amplifiers. Wirelessly connected amplifiers can be placed at a distance from the patient's head without wires 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 strongly 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 320x240 or 640x480 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 ICU 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: electro-oculogram (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 x 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 is system is used for remote CCEEG monitoring, it is suggested that its 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 x number of acquisition machines x number of days data are stored before archiving). Example: 12 GB/day (video + EEG) x 8 machines x 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. Severs 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 is 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.

V. CCEEG PROCEDURES

A. Patient Selection and Triage

1. ***CCEEG programs should have written protocols 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. Protocols 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. Examples of protocol patient populations in whom CCEEG is typically recommended can be found in the online supplement table 2.
   a. Known NCS or NCSE

1) Illness severity: Subclinical or refractory seizures and status epilepticus
2) Purpose of monitoring: Identification of NCS, confirmation of treatment efficacy
3) Recording duration:
    a) Suspected NCS: discontinue after 24-48 hours if no seizures occur
    b) Confirmed NCS: discontinue 24 hours after last seizure occurred
    c) Refractory NCSE: discontinue 24 hours after cIV-ASDs are stopped
4) Quantitative EEG: seizure detection methods, measures of burst suppression

b. Traumatic brain injury
    1) Illness severity: Glasgow Coma Score (GCS) ≤ 10 and/or intracranial hemorrhage
    2) Purpose of monitoring: Detection of NCS
    3) Recording duration: Begin as soon as feasible, discontinue after 24-48 hours if no seizures occur; can be requested for additional 48 hours as sedating medications weaned
    4) Quantitative EEG: seizure detection methods
c. Intracerebral hemorrhage
    1) Illness severity: Any alteration in awareness
    2) Purpose of monitoring: Detection of NCS
    3) Recording duration: Begin as soon as feasible, discontinue after 24-48 hours if no seizures detected; can be requested for additional 48 hours if sedating medications weaned
    4) Quantitative EEG: seizure detection methods
d. Hypothermia after cardiopulmonary arrest
    1) Illness severity: Coma after cardiac arrest undergoing hypothermia protocol (altered mental status following cardiopulmonary arrest)
    2) Purpose of monitoring: Detection of NCS, prognostication
    3) Recording duration: Begin as soon as feasible, preferably before hypothermia is initiated; discontinue 24 hours after end of hypothermia
    4) Quantitative EEG: seizure detection methods, measures of burst suppression
e. Aneurysmal SAH
    1) Illness severity: Fisher grade 3 or 3/4, Hunt & Hess grades 3, 4, 5
    2) Purpose of monitoring: Detection of ischemia / vasospasm; detection of NCS
    3) Recording duration: Begin on SAH day #2 after treatment of aneurysm, optimal duration not identified but if resources allow, consider recording through day #14 or discharge from the ICU
    4) Quantitative EEG: seizure detection methods, ischemia methods

3. Several other patient populations may be candidates for CCEEG, but there is limited evidence supporting the benefit of CCEEG. These requests should be considered on an individual basis, with examples below:
    a. Management of elevated intracranial pressure; monitoring level of

sedation
   1) Illness severity: ICU patient requiring sedation with continuous intravenous anesthetic agent
   2) Purpose of monitoring: Titration of sedation to minimize adverse hemodynamic effects
   3) Recording duration: Need for continued monitoring should be discussed with EEG team daily
   4) Quantitative EEG: seizure detection methods, measures of burst suppression
b. Other acutely ill neurologic patients
   1) Illness severity: Coma or obtundation
      a) Post neurosurgical procedure with altered mental status, for NCS
      b) Large ischemic stroke, for worsening ischemia
   2) Purpose of monitoring: Varies with indication
   3) Monitoring duration: Need for continued monitoring should be discussed with EEG team daily
   4) Quantitative EEG: seizure detection methods, measures of burst suppression, ischemia methods

B. Initiation of CCEEG

1. ***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 protocols 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.
2. 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.

3. 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. 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.

4. 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.

5. 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.
6. 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.
7. EEG quality. Prior to initiation of recording, the NDT should perform an impedance check and evaluate for presence of artifacts. Initial impedance should be less than 5000 ohms.
8. 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.
9. NDTs should collect relevant clinical data from ICU staff and the medical record, such as patient history, level of consciousness, recent procedures, medications including sedation, and other monitoring techniques in use. NDTs should prepare a brief summary of clinical data.
10. NDTs should remain at the bedside for the first 30 minutes of recording, to evaluate for EEG patterns requiring urgent interpretation, to examine patient behavior, and to ensure good 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.

11. 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 ICU EEG 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 detect 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.***
5. ***Reactivity should be assessed daily.*** Optimally, this 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 / 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 plastics used in other neuromonitoring devices. 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. ***Quantitative EEG trends should be incorporated into CCEEG clinical workflows, but cannot be interpreted in isolation from raw EEG.*** Computer processing of digital EEG data can make CCEEG review less time-consuming and may also 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). 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 at the bedside 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). 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 cannot describe all 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 detect 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 detect 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 detection.
    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, particularly 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, Shiau 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 frequently as possible (at least twice daily) for data quality and important EEG changes.*** Behavioral and EEG observation can be performed at the bedside or remotely via hospital networks, and by a variety of ICU and EEG staff.
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. 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.
4. Quantitative EEG 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.
5. Remote central continuous monitoring. This is the optimal means of correlating behavior with EEG features, assessing possible sources of artifact, and detecting 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 detection 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 and NDTSs 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 technologist 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 ratio of 1 NDT to 6 or 8 displays 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 quantitative EEG 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.

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.*** Reports should be written at least daily, and should clearly describe any EEG and video events. Interim reports should be issued to the clinical care team when important changes occur. These can be verbal or written. 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, 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.
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 added or stopped, interim procedures, and results of testing such as CT, MRI, and Transcranial Doppler. 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.
5. CCEEG electroencephographers 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 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 quantitative EEG 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.

VI. CONCLUSION

CCEEG is an emerging technique to identify secondary brain injuries such as seizures and ischemia in critically ill patients. There is increasing evidence that these secondary injuries can worsen neurologic outcome, although no prospective studies have yet demonstrated that treatment of EEG-identified changes improves neurologic outcome. The most common indication for CCEEG is for identification of NCS and NCSE, with ischemia detection and prognostication as less common uses. 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.

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