neurocritical care society Neurocrit Care
DOI 10.1007/s12028-009-9248-2

TAKE NOTICE TECHNOLOGY

Seizure Detection with a Commercially Available Bedside EEG Monitor and the Subhairline Montage

G. Bryan Young · Michael D. Sharpe · Martin Savard · Eyad Al Thenayan · Loretta Norton · Corrine Davies-Schinkel

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Abstract

Introduction Availability of standard, continuous electroencephalography (cEEG) monitoring in ICU is very limited, although commercially available 4-channel modules are present in many ICUs. We investigated the sensitivity of such modules compared with the more complete monitoring with a standard EEG system.

Methods Seventy patients at high risk of seizures in the medical-surgical intensive care unit and Epilepsy Monitoring Unit were recorded simultaneously for at least 24 h with a 4-channel commercial ICU bedside monitoring system (Datex-Ohmeda) with a subhairline montage and a standard EEG machine (XLTEK) using the international 10-20 system of electrode placement. Recordings were interpreted independently from each other.

Results The 4-channel recordings demonstrated a sensitivity of 68 and 98% specificity for seizure detection, and a sensitivity of 39% and a specificity of 92% for detection of spikes and PLEDs.

Conclusions The 4-channel EEG module has limited but practical usefulness for seizure detection when standard cEEG monitoring is not available.

Keywords Acute brain injury · Seizures · Continuous electroencephalography · Subhairline montage

Supported in part by GE Healthcare.

G. B. Young (✉)
Department of Clinical Neurological Sciences, The University of Western Ontario, Room B10-106, University Hospital, 339 Windermere Rd, London, Ontario N6A 5A5, Canada
e-mail: bryan.young@lhsc.on.ca

M. D. Sharpe
Department of Anesthesia and Perioperative Medicine, The University of Western Ontario, London, Ontario N6A 5A5, Canada

M. Savard · E. Al Thenayan
Program in Neurocritical Care, The University of Western Ontario, London, Ontario N6A 5A5, Canada

L. Norton · C. Davies-Schinkel
Program in Critical Care, The University of Western Ontario, London, Ontario N6A 5A5, Canada

Introduction

In comatose patients, the clinical examination is often an unreliable monitor of cerebral cortical function, yet the cerebral cortex is subject to further damage from seizures and/or ischemia, particularly in patients with acute brain injury [1]. The advent of digital EEG has provided an opportunity to assess cerebral cortical function in real time at the bedside. More than 90% of seizures in comatose ICU patients are nonconvulsive and therefore, cannot be diagnosed reliably without an EEG. Since the majority of these seizures also occur within the first 48 h of brain injury, early application of continuous electroencephalography (cEEG) is necessary in order to detect and treat nonconvulsive seizures [2]. Early detection of seizures is also important since mortality also increases exponentially with seizure duration [3–5].

However, the ability to perform EEG monitoring is not present in many hospitals, or it is delayed in its application, as it requires trained technicians and equipment, which are often not immediately available. With the introduction of digital, bedside EEG modular technology, and the application of a subhairline montage utilizing stick-on surface electrodes, which can be easily applied by the bedside ICU nurse, prompt, cEEG monitoring for high risk patients is now feasible [6]. We sought to determine the accuracy of this new technology, by comparing it to standard 16-channel EEG monitoring, for detection of seizures, spikes, and periodic lateralizing epileptiform discharges (PLEDS), in patients at high risk of seizures.

Methods

With approval from our institutional Research Ethics Board for Health Sciences Research Involving Human Subjects and signed consent, we studied 70 patients admitted to our medical-surgical intensive care unit or epilepsy unit either with seizures or with acute brain injury.

cEEGs were simultaneously recorded for 24 h with a standard 16-channel EEG monitor (XLTEK EEG, Canada) using the International 10-20 system [7] and tin disk scalp electrodes attached with collodion, and a 4-channel bipolar EEG monitor (Datex-Ohmeda S/5 M-EEG Module; model #898683-00 plugged in Datex-Ohmeda Critical Care monitor, GE Healthcare, Helsinki, Finland) using skin surface electrodes (Zipprep #186-0023, Aspect Medical Systems, Inc., Norwood, MA) and a subhairline montage [6] (Fig. 1). The recordings were coded by number (without patient identification) and archived onto CD ROM disks. The XLTEK and Datex-Ohmeda recordings were interpreted by GBY or MS and were interpreted usually more than a month after they were archived, with the interpreters blinded to the identity of the patients. The two EEG recordings from each patient were reviewed independently of one another and the reader was unaware of the results of the other simultaneous EEG recording. The XLTEK recordings were considered the “gold standard” for comparing the Datex-Ohmeda recordings.

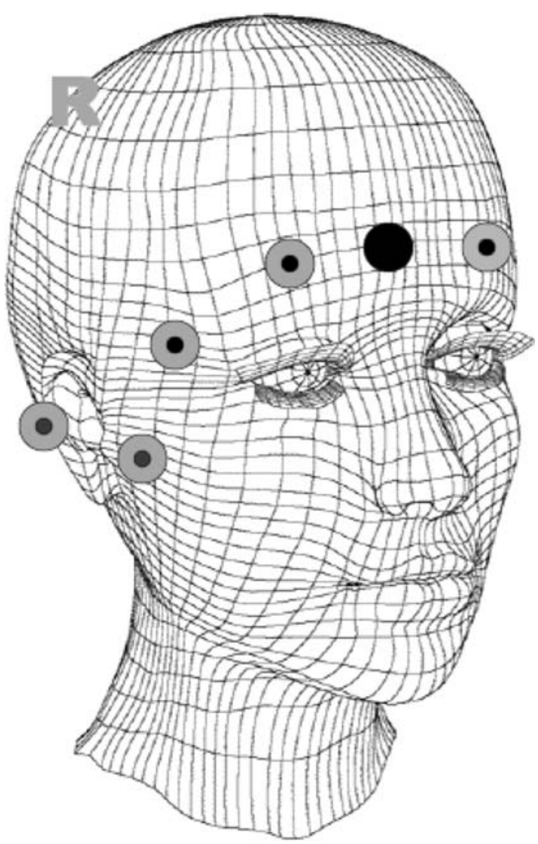

Fig. 1 Placement sites of adhesive electrodes for SHM

Analysis

The EEG recordings were classified according to standard nomenclature previously described and, whether or not, focal or generalized seizures, spikes, or PLEDs were identified. When a discrepancy in classification occurred between the two observers for any single recording, the EEG was reviewed by both readers together to arrive at a consensus. Calculation of sensitivity and specificity were performed for seizure activity and epileptiform spike/PLED activity by constructing 2 × 2 tables as depicted in Table 1.

Results

The diagnostic categories and EEG results are detailed in Table 2. The study group consisted of 70 patients (26 females) with an average age of 53 ± 18 (range 20–85) years. The most common ICU admission diagnosis was metabolic disorder (e.g., organ failure/sepsis). Nineteen (27%) patients were admitted to the ICU (14 patients) or epilepsy unit (5 patients) with a primary diagnosis of seizures. Seizures were detected in 31% ($n = 22$) of patients using standard 16-channel XLTEK cEEG and only 15/22 of these seizures were detected using the Datex-Ohmeda, modular, bedside technology (sensitivity = 68%; 95% confidence interval [95% CI] 45–86%). One of the Datex-Ohmeda recordings was interpreted as showing a seizure when the XLTEK recording of the same patient did not (specificity = 98%; 95% CI 89–100%. The positive predictive value (PPV) of the Datex-Ohmeda system was 94%

Table 1 Calculation of sensitivity and specificity

		XLTEK seizure	
		Yes	No
Datex-Ohmeda seizure	Yes	*a*	*b*
	No	*c*	*d*

Sensitivity = $a/(a + c)$

Specificity = $d/(b + d)$

Table 2 Diagnostic categories and seizure detection

Diagnosis (number of cases)	XLTEK-recorded seizures	Datex-recorded seizures
Seizure disorder (Epilepsy—19)	8	6 (1 false positive)
Metabolic (organ failure/sepsis—21)	2	2
Neurosurgical post-op for tumor (8)	1	1
Trauma (4)	2	1
Cardiac arrest (4)	1	1
Ischemic stroke (5)	4	2
CNS infection (3)	1	1
Intracerebral hemorrhage (2)	2	1
Drug intoxication (2)	1	1
CNS vasculitis (1)	0	0
Hypertensive encephalopathy (1)	0	0

(95% CI 70–100%) and its negative predictive value (NPV) was 87% (95% CI 75–95%). The net results are shown in Table 3.

The failure of detection of seizures using the subhairline montage was not related to location of seizures since in this group of patients, the subhairline montage detected seizures arising from all lobes of the cerebral hemispheres, as confirmed by the standard EEG.

Examples of simultaneous XLTEK and Datex-Ohmeda recorded seizures are shown in Figs. 2 and 3. As seen, the quality of the recording is not as distinct with the Datex-Ohmeda system and there was abundant EKG contamination; detecting an evolutionary pattern prior to a seizure was helpful in identifying seizures.

The Datex-Ohmeda system was positive for spikes or PLEDs in only 12 of the 31 detected with the XLTEK system (sensitivity = 39% (95% CI = 22–58%). Three cases were false positive for spikes with the Datex-Ohmeda system. The specificity for spikes or PLEDs was 92% (95% CI 79–98%); PPV was 80% (95% CI 52–96%); and NPV was 65% (95% CI 51–78%) (Table 4).

Table 3 Seizure detection

	Standard EEG positive	Standard EEG negative	Total
Datex positive	15	1	16
Datex negative	7	47	54
Total	22	48	70

Datex bedside module with SHM; *Standard EEG* 18-channel recordings with XLTEK digital EEG machine

Discussion

Our study demonstrated the application of a commercially available, bedside, 4-channel cEEG module, using a bipolar subhairline montage, was capable of detecting 68% of seizures, as by standard EEG technology. The new technology facilitates early monitoring of the brain in patients with acute brain injury and at high risk of seizures.

Kolls and Husain performed a study somewhat similar to ours, using modifications of the subhairline montage by reformatting standard digital EEG recordings and reading them blindly, while comparing to standard montages [8]. With respect to seizure and spike detection, not surprisingly, they concluded that the subhairline montage was inferior to standard EEG for long-term ICU recordings, as the sensitivity of detecting seizures and spikes/PLEDs was only 72 and 53%, respectively. Our findings demonstrated sensitivity rates of 68 and 39%, for detection of seizures and spikes/PLEDs, respectively. However, there are some important differences between their study and ours: (1) they did not apply electrodes below the hairline (see Fig. 1), but used the 10-20 system of placement; (2) they used standard commercial EEG equipment for recording, rather than the bedside cEEG module used in our study. Note that the Datex-Ohmeda module sampling rate is only 100 Hz, while standard EEG machines sampling rates are over 200 Hz; the lower sampling rate makes identification of apiculate waveforms problematic [9]. We also found significant EKG contamination throughout our subhairline recordings, which created problems with interpretation, even with a bipolar montage. The Datex-Ohmeda Critical Care monitor is equipped with EKG measurement. However, EKG signal was not utilized in off-line analysis by GBY and MS and that may have some effect for the results. Nonetheless, our findings were similar to theirs. There were few false positives in either our study (specificity 98%) or theirs (specificity 87–99%, depending on montage). Thus, one is not often misled by false determinations of seizure activity.

We disagree with Kolls and Husain in their rejection of the value of cEEG with the hairline/subhairline montage. We concur that cEEG is useful when there is a high pretest probability of finding seizures (e.g., acute brain injury) and management is facilitated at times when standard EEG is not available. Detection of approximately 70% of nonconvulsive seizures is better than detecting none, which is the case in many ICUs, where long-term monitoring is not feasible and even standard, 20–30 min recordings are not available on weekends and evenings. Also, temporal lobe structures, especially the hippocampus and amygdala, are the most vulnerable sites for epileptic brain damage [10]; these structures should be covered equally well by subhairline and standard EEG montages.

Fig. 2 **a** Sequential frames of a seizure maximally expressed in the left posterior head (the odd numbered channels, e.g., involving electrodes C3, P3, F7, T3, T5, and O1, are from the *left* hemisphere). The first frame is on the *left*, the next the *upper right* and the third is on the *lower right*. Note the evolutionary changes in morphology, amplitude, and frequency that characterize the seizure. **b** The same seizure recorded with SHM, using the same arrangement of sequential frames as in **a**. The first and third channels are from the *left* hemisphere. Note that the evolutionary changes of the seizure are recognizable, but there is abundant EKG artifact

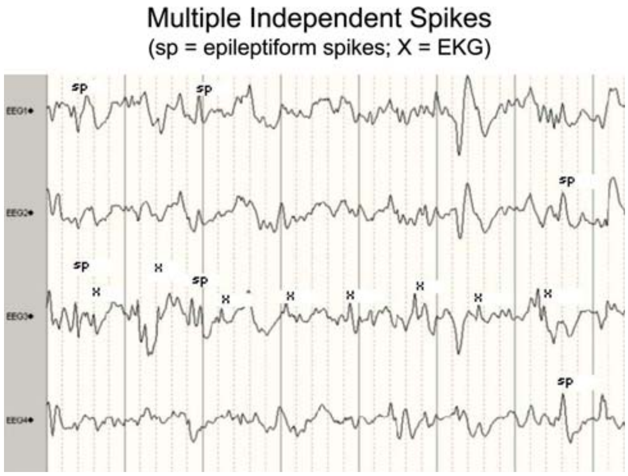

Fig. 3 SHM tracing showing epileptiform spikes and EKG contamination. It was often difficult to differentiate between them, especially with ectopic or irregular cardiac rhythms

Table 4 Spike or PLEDs detection

	Standard EEG positive	Standard EEG negative	Total
Datex positive	12	3	15
Datex negative	19	36	55
Total	31	39	70

In addition, having cEEG allows one to monitor the effect of treatment, e.g., achieving an appropriate level of burst-suppression level of sedation/anesthesia for the management of status epilepticus, thus preventing both over-treatments, with prolonged sedation and hemodynamic instability, and/or under-treatment, with prolonged, unrecognized nonconvulsive seizures/status epilepticus [11, 12]. When cEEG is not available, monitoring of adequate levels of therapy becomes an estimate at best.

Other technical challenges of cEEG in the ICU include the type of scalp electrodes used. An electrode that is easily and quickly applied, without the need for collodion, with stable impedance over time, is ideal. Standard 1 cm diameter scalp disk electrodes applied with collodion begin to fail within the first 6 h of ICU recordings [13]. Although subdermal wire electrodes are superior, electrocardiographic (EKG) stick-on electrodes, or in our study, the use of stick-on electrodes designated for EEG use, can provide adequate recordings with a subhairline montage for up to 48 h [14].

The development of bedside cEEG technology, using a subhairline montage that is easily and quickly applied by the ICU nurse, is crucial to facilitate monitoring of the cerebral cortex in patients who present with seizures or an acute brain injury which predisposes patients to seizures. Although the current technology is superior than having no access to cEEG, we need to strive for technological improvements that will result in an increase in the detection rate of seizures, interictal discharges, burst-suppression, and various EEG frequencies. For instance, better sampling rates, the use of filters to minimize EKG and EMG artifact, alarms for electrode failure/mismatched impedances, better electrodes and, combined with an electronic algorithm to aid in the interpretation of seizures/dysrhythmias and the assessment of the effects of treatment are needed. It also seems reasonable to develop simplified EEG appliances and the use of MRI and CT-compatible electrodes, since many of these patients require frequent/multiple imaging [15, 16]. Overall, this should provide better and more consistent results for CEEG monitoring in the ICU, with ultimate improvement in patient outcome.

References

1. Jordan KG. Neurophysiologic monitoring in the neuroscience intensive care unit. J Clin Neurophysiol. 1995;13:579–626.
2. Claassen J, Mayer SA, Kowalski RG, Emerson RG, Hirsch LJ. Detection of nonconvulsive seizures with continuous EEG monitoring in critically ill patients. Neurology. 2004;62:1743–8.
3. Young GB, Jordan KG, Doig GS. An assessment of nonconvulsive seizures in the intensive care unit using continuous EEG monitoring: an investigation of variables associated with mortality. Neurology. 1996;47:83–9.
4. Vespa PM, Miller C, McArthur D, Eliseo M, Etchepare M, Hirt D, et al. Nonconvulsive electrographic seizures after traumatic brain injury result in a delayed, prolonged increase in intracranial pressure and metabolic crisis. Crit Care Med. 2007;35:2830–6.
5. Vespa PM, Nenov V, Nuwer MR. Continuous EEG monitoring in the intensive care unit: early findings and clinical efficacy. Am Clin Neurophysiol Soc. 1999;16:1–13.
6. Bridgers SL, Ebersole JS. EEG outside the hairline: detection of epileptiform abnormalities. Neurology. 1988;38:146–9.
7. Jasper HH. The 10-20 electrode system of the International Federation. Electroenceph Clin Neurophysiol. 1958;10:371–5.
8. Kolls BJ, Husain AM. Assessment of hairline EEG as a screening tool for nonconvulsive status epilepticus. Epilepsia. 2007;48:959–65.
9. McLachlan R, Young B. Minimal standards for digital/quantitative electroencephalography in Canada. Can J Neurol Sci. 1999;26:153.
10. Young GB, Doig GS. Continuous EEG monitoring in comatose ICU patients: epiletptiform activity in etiologically distinct groups. Neurocrit Care. 2205;2:5–10.
11. Savard M, Al Thenayan EA, Norton L, Sharpe MD, Young B. Continuous EEG monitoring in severe Guillan-Barre syndrome patients. J Clin Neurophysiology. 2009;26:21–3.
12. Mirsattari SM, Sharpe MD, Young GB. Treatment of refractory status epilepticus with inhalational anesthetic agents Isoflurance and Desflurane. Arch Neurol. 2004;61:1254–9.
13. Young GB, Ives JR, Chapman MG, et al. A comparison of subdermal wire electrodes with collodion-applied disk electrodes in long-term EEG recordings in ICU. Clin Neurophysiol. 2006;117:1376–9.

14. Hunter G, Young B, Davies-Schinkel C. Comparison of adhesive-backed electrodes with conventional disk electrodes for long term EEG recordings in the ICU. J Clin Neurophysiol. (in press).
15. Foldvary N, Caruso AC, Mascha E, et al. Identifying montages that best detect electrographic seizure activity during polysomnography. Sleep. 2000;23:221–9.
16. Mirsattari SM, Davies-Schinkel C, Young GB, et al. Usefulness of a 1.5T MRI-compatible EEG electrode system for routine use in the intensive care unit of a tertiary care hospital. Epilepsy Res. 2009;84:28–32.