ELECTROENCEPHALOGRAPHY IN THE INTENSIVE CARE UNIT: A TECHNICAL ASSESSMENT

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ABSTRACT

Intensive Care Unit (ICU) clinicians currently rely on visual cues and vital sign fluctuations as a means of detecting non-convulsive seizures in their patients. It has been proposed that continuous electroencephalography (cEEG) monitoring be employed to examine ICU patients for non-convulsive seizures. A study conducted at Victoria General Hospital in Victoria, BC opted for a multi-channel cEEG monitoring system and overcame logistical, technical and financial challenges to permit the introduction of this unfamiliar technology into the ICU. Creating a working group that united experts with a vested interest in improving patient care was crucial to this study's success.

INTRODUCTION

The damaging effects of epilepsy are well known to physicians, nurses and encephalographers. While seizures are generally the result of neurologic complications associated with a pre-existing illness, patients admitted to the ICU rarely have a prior history of seizures or neurologic pathology.[1] Many of these seizures have been reported to be non-convulsive in nature; meaning there are not motor manifestations (convulsions) to visually indicate a seizure is occurring.[1,5,6,7,14,15] Victoria General Hospital (VGH) in Victoria, British Columbia undertook a study to assess the feasibility of implementing continuous electroencephalography (cEEG) monitoring in the ICU to detect non-convulsive seizures.

BACKGROUND

Monitoring in the VGH ICU for signs of consciousness and/or symptoms of a seizure is currently done at regular intervals with neurological checks: pupils, Glasgow Coma Scale, blood pressure, pulse, respiration, cerebral perfusion pressure, intra-cranial pressure and limb movements. At VGH, when a seizure or deteriorating neurologic function is suspected, a bedside electroencephalography (EEG) evaluation is ordered. An electrodiagnostic (EDS) technician (encephalographer) would postpone their appointments and respond to the ICU request. After setting up the EEG equipment, a 30 minute "snapshot" of the brain would be taken.[15] This method of screening for seizures is disruptive to the EDS department, its patients, and often provides inadequate information and may miss the neurologic event(s) altogether.[15] Clinical decisions could be made based on the "snapshot" recording, yet monitoring the treatment would not persist due to a 30 minute time limit for EDS services. cEEG monitoring offers a unique means of tracking neurologic function and with a well trained staff, help prevent further patient deterioration.[12,15]

Since the mid 1990s, more reporting and implementation of EEG monitoring in the ICU has been requested. Jordan, Ronne-Engstrom, Young, Vespa and Claassen have spent many years accumulating patient data and building a case for cEEG in the ICU. Their work, results and that of others are summarized in Table 1.

Table 1: Patient type, patient seizure percentage and detection timeframe from various authors

Author	Patient Type	Seizure %	Timeframe
Jordan (1993)	Neuro-ICU	34%	-
Jordan (1999)	Neuro-ICU	-	4.2 days
Ronne-Engstrom & Winkler (2006)	TBI	33%	72 ±47 hrs
Young & Doig (2005)	General ICU	11%	-
Vespa et al. (1999)	Head Injury	22%	-
Abou Khaled, Karine J. and Hirsch (2007)	General ICU	19%	non comatose: 24 hrs , comatose : 48 hrs
Fountain (2007)	TBI	20%	3 days
Claassen et al. 2004	General ICU	19%	93% detected within 48 hrs

TBI: Traumatic Brain Injury, Neuro-ICU: Neuroscience ICU

Although the patient types from the above studies have varied, the most common causes of primary neurologic disorders resulting in non-convulsive seizures are ischemic stroke, intracranial tumors, and traumatic brain injuries.[1,5,7,11,12,14,15]

The long-term burden of traumatic brain injury (TBI) in terms of direct care costs and lost productivity to society are staggering and the importance for early

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detection and immediate treatment have been documented.[1,6,7,8,11,12,15]. cEEG is the only technology available for long-term continuous monitoring and detection of non-convulsive epileptic activity.[7,15] Its live feed shows seizures as they happen, providing physicians with an opportunity to stop the seizures and limit cell damage immediately.[11,12] Treatment can help to promote patient recovery and reduce hospital stay times.[9]

METHODS

In order to assess the viability of introducing cEEG monitoring in the ICU, a feasibility study focused on identifying technical challenges associated with detection effectiveness and equipment technology. Logistical and financial matters that include clinician training, equipment costs and staffing were also addressed.

Detection Effectiveness of cEEG

ICUs contain a large quantity of equipment that occupies space and produces a lot of electrical noise.[2, 10,12,15] Compared to a conventional EEG laboratory, artifacts of biologic, electrical, and environmental sources are experienced more frequently.[15] Artifacts can arise from IVs and ventilator tubing, while multiple ground paths for current are available.[10,15] Other challenges to be faced while undertaking long term recordings are the possibilities of electrode contact failures from drying out, impedance mismatches, altered cranial anatomy, open wounds, and patient movement.[2,10,15] Combine these obstacles, with reports of recording times lasting several days, and reviewing days of raw EEG data appeared to be a very complicated undertaking.[5,6,7,14,15]

Consulting the Experts

The next step was to hold discussion with the ICU clinicians and nurses to assess their interest in cEEG, determine their EEG expertise and whether other expert involvement was required. Three departments at VGH (ICU, Neurology and Biomedical Engineering) possess unique knowledge and expertise deemed vital to the project. ICU physicians had no experience reading EEG waveforms, while encephalographers were accustomed to monitoring out-patients that are recognized epileptics or are suspected of having seizures.[9] Biomedical Engineering, which spearheaded the initiative, took responsibility for logistics and planning as well as exploring and explaining the technical characteristics of the EEG equipment.

Equipment Selection

A work group comprising of one individual from each department was established to assess the viability of using a Philips Healthcare 2-channel cEEG module purchased during an equipment upgrade in 2005. The module integrated directly into the ICU's patient monitoring system. A Stellate Vita system was also considered following the 2-channel evaluation. The 2-channel EEG system displayed raw EEG waveforms as well as a compressed spectral array (CSA). CSA transforms the raw EEG recording into frequency and power measurements which are derived primarily from a mathematical formula for wave subgroup analysis called the fast Fourier transform.[15]

EEG Technology: 2-Channel Monitoring

Literature acknowledges the potential for this quantitative method of monitoring stating that integration of CSA may ease the review process by summarizing minutes or hours of data into the monitoring screen permitting ICU nurses and physicians to obtain information at a single glance.[12] Gradual changes over time become clear.[16] Given that the EEG module integrates directly into the networked patient monitoring system, there was hope that other physiologic data could be used to establish relationships between it and the EEG.[12,13] Physicians and nurses would be able to make quick identification of changes from CSA trends.[16] Unfortunately, the original digital EEG tracings were unable to be saved on the monitoring system unless a large number of primary vital signs were switched off or large scale system reprogramming was done. The functionality of the 2-channel system was extremely limited by this characteristic.

Traditional EEG artifacts can appear on the CSA in unusual ways and impair adequate interpretation of raw data.[2,16] There were also reports of problems with the recommended sub-hairline electrode montages for the 2-channel system. Locations that include forehead (Fp_1, Fp_2), behind the ears (T_3, T_4) and the occipital (O_1, O_2) are all subject to producing muscle or motion artifacts.[16] Multi-channel EEG not only provides more local data that facilitates diagnosis by an encephalographer, but also assists with isolation and elimination of artifacts. Figure 1 highlights the difference in contact points between a 2-channel and 10-20 electrode montage. Making clinical decision from the 2-channel system was unfeasible for encephalographers and neurologists.

EEG Technology: Multi-channel Monitoring

What was needed was a stand alone multi-channel cEEG system that was easy to use for ICU staff while providing encephalographers and neurologists with the ability to review and classify raw EEG data.[12] Commercial systems with automated spike and seizure detection algorithms facilitate interpretation for the ICU worker while tagging the suspected event for review by an experienced encephalographer.[12,13,15] This function reduces the large volume of cEEG data into a manageable portion and provides real life cases for a continuing learning program.[13]

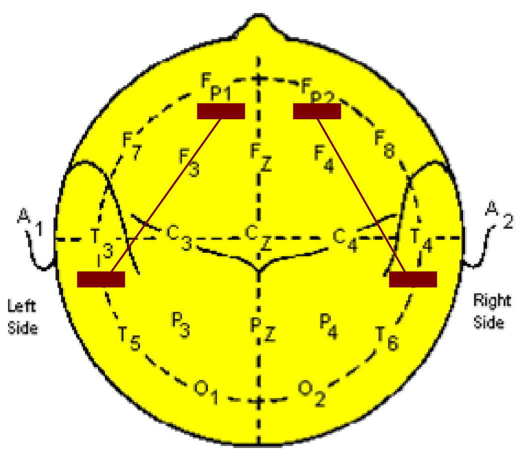

Figure 1: Location of electrode sites for a standard 10-20 EEG montage. Underlined is a recommended 2-channel monitoring system montage.[19]

While the ICU is staffed 24-7, encephalographers and neurologists at VGH generally worked from 8am to 4pm, but were on call in case of emergencies. A major concern needing to be addressed from the ICU was what will happen at 4am on a Saturday when a critical decision needs to be made. Emphasis on timely and accurate diagnosis of pathophysiologic events and treating them as they occur was an utmost priority.[12,15] Remote network access was critical to the success of this project.[10,13,15] The Stellate Vita cEEG system integrated seamlessly via wireless communication to the Neurology network that was already setup for remote access from terminals within the Neurology and EDS departments and at select neurologist's homes.

Electrode Selection

The final technical hurdle to overcome was the selection of electrodes. Skin electrode interface has always been the weak link in EEG technology.[13] Three choices were available and although a final decision had not been made at the conclusion of the study, the choice of electrode plays an important role in the successful implementation of cEEG. Strengths and weaknesses for traditional cup electrodes, stick-on electrocardiogram (ECG) electrodes, and needle electrodes are considered in Table 2.

Table 2: Strengths and weaknesses of electrode candidates

Electrodes	Strengths	Weaknesses
Cup	-High Sensitivity -Familiarity	-6-12 hr lifespan -Strong collodion smell, flammable -Removal required for cerebral imaging
Stick-on	-Readily Available -Low Cost -Good Adhesive Properties	-24 hr lifespan -Higher impedance -Removal required for cerebral imaging
Needle	-Excellent recording characteristics -Long term use -Removal not required for imaging	-Invasive -High cost

Cup electrodes might seem the best choice given that the Neurology department accepted the responsibility of applying the electrodes and they are familiar with the product. However, the average lifespan of cup electrodes is 6-12 hours.[18] Maintenance of electrode connections would require constant supervision from the Neurology department. Also, the compound used to secure the electrodes to the scalp, collodion, has a very strong, unpleasant smell and is flammable. Removal of collodion is done with acetone, another strong smelling, highly flammable compound. The ICU was not interested in the compounds fearing complaints from families, an unwelcoming environment and added stress. ECG electrodes have double the lifespan of cup electrodes, are readily available and low cost, however reapplication will be necessary and experience showed that achieving the low impedance necessary for recording was quite arduous.[10] Should the patient have any open wounds or fractures, application could not take place. This study's final recommendation was for the use of subdermal needle electrodes. Despite their high cost and invasive nature, needle electrodes can be easily affixed with surgical tape and/or head bandages and left in place for days at a time.[7,13] They have a very low impedance as they directly contact live tissue, and also where the other candidates require removal for cerebral imaging, needle electrodes do not.[13]

Cost Considerations

cEEG monitoring has cost implications for the technology, maintenance, training and continuing education, as well as the dedicated technologist for electrode application, waveform review, and after hours consultations.[9,13,15] In order to implement a cEEG monitoring program, it must provide a cost benefit to the institution and the public in the form of lives saved and cost savings. Literature from Vespa et al. reported monitoring costs of $560 per patient, but an average decline in patient cost from $88,690 to $49,578) and reduced patient stay from 24.3 days to 13.6 days.[12] Jordan et al. also reported cost reductions of $4,000 per CEEG patient.[15]

In order to guarantee the success of cEEG, the Neurology and ICU departments agreed to share costs related to the program. Costs for the technologist would be taken on by the Neurology department. They would also file a capital request to purchase the cEEG monitor and be responsible for its maintenance and upkeep. Consumables, training programs, and after hours support costs would be the responsibility of the ICU. At an initial cost of approximately $60,000 per machine, the establishment of the cEEG program at VGH fits within the estimated costs of $100,000 to $150,000 estimated by Jordan et al.[15]

CONCLUSION

Monitoring brain function is as critical as monitoring heart, lungs, and other organ functions.[9] Further efforts to expand the current system of clinical observations to include cEEG monitoring will help build a new standard of neurological care in the ICU.[9] Support for a cEEG program at VGH is strong and has continued to move forward following the conclusion of this study. Trials have been conducted in both the adult and neonatal intensive care units and have received favorable reviews. Once the capital for the technology has been approved and the system installed, all parties involved will have made a commitment to improving patient care. Success depends on the proficiency of bedside nurses, encephalographers, neurologists and attending physicians to analyze the data, communicate observations, and make accurate decisions.[15] Efficacy involves the ability to make a difference in patient care and outcome.[12]

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REFERENCES

[1] Mirski, Marek A. et al. “Seizures and status epilepticus in the critically ill,” *Critical Care Clinics,* Vol. 24, pp.115-147, 2008.

[2] Kaplan, Peter W., “EEG monitoring in the Intensive Care Unit,” *American Journal of Electroneurodiagnostic Technology*, Vol. 46, pp.81-97, 2006.

[3] Aminoff, Michael J.et al., Greenberg, David A. and Simon, Roger P., “Seizures and Syncope,” in *Clinical Neurology,* 6th ed., McGraw-Hill Medical, 2005, pp.265-266.

[4] McCance, Kathryn L. and Huether, Sue E., “The Neurologic System,” in *Pathophysiology – The Biologic Basis for Disease in Adults and Children*, 3rd ed., Mosby Elsevier Health Science, 1997, pp.470-472.

[5] Abou Khaled, Karine J. and Hirsch, Lawrence J., “Advances in the management of seizures and status epilepticus in critically ill patients,” *Critical Care Clinics*, Vol. 22, pp. 637-659, 2007.

[6] Fountain, Nathan B., “Is it time for routing EEG monitoring after intracerebral hemorrhage,” *Neurology*, Vol. 69, pp 1312-1313, 2007.

[7] Ronne-Engstrom, E. and Winkler, T., “Continuous EEG monitoring in patients with traumatic brain injury reveals a high incidence of epileptiform activity,” Acta Neurologica Scandinavica, Vol. 114, pp. 47-53, 2006.

[8] Ling, Geoffrey S.F. and Marshall, Scott A., “Management of Traumatic Brain Injury in the Intensive Care Unit,” *Neurologic Clinics*, Vol. 26, pp. 409-426, 2008.

[9] Young, G.B., “Continuous EEG monitoring in the ICU,” Acta Neurologica Scandiavica, Vol. 114, pp. 67-68, 2006.

[10] Young, G. Bryan and Campbell, Vanessa C., “EEG monitoring in the Intensive Care Unit: pitfalls and caveats,” *Journal of Clinical Neurophysiology*, Vol. 16, pp. 40-45, 1999.

[11] Young, G. Bryan and Doig, Gordon S., “Continuous EEG monitoring in comatose intensive care patients: epileptiform activity in etiologically distinct groups,” *Neurocritical Care*, Vol.2, pp. 5-10, 2005.

[12] Vespa, Paul M. et al., “Continuous EEG monitoring in the Intensive Care Unit: early findings and clinical efficacy,” *Journal of Clinical Neurology*, Vol. 16, pp. 1-13, 1999.

[13] Kull, Lewis L. and Emerson, Ronald G., “Continuous EEG monitoring in the Intensive Care Unit: technical and staffing considerations,” *Journal of Clinical Neurology*, Vol. 22, No.2, 2005.

[14] Claassen, J. et al., “Detection of electrographic seizures with continuous EEG monitoring in critically ill patients,” *Journal of Neurology*, Vol. 62, pp. 1743-1748, 2004.

[15] Jordan, Kenneth G. et al., “Continuous EEG monitoring in the neuroscience Intensive Care Unit and Emergency department,” *Journal of Clinical Neurophysiology*, Vol. 16, No. 1, pp 14-39, 1999.

[16] Nuwer, Marc, “Assessment of digital EEG, quantitative EEG, and EEG brain mapping: Report of the American Academy of Neurology and the American Clinical Neurophysiology Society,” *American Academy of Neurology*, Vol. 49, No.1, pp. 277-292, 1997.

[17] Towne, A. R., et al. “Prevalence of non-convulsive status epilepticus in comatose patients,” *American Academy of Neurology*, Vol. 54, No.2, pp. 340, 2000.

[18] Young, G. Bryan, Ives, John I., Chapman, Martin G., Mirsattari, Seyed M., “A comparison of subdermal wire electrodes with collodion-applied disk electrodes in long-term EEG recordings in ICU,” Clinical Neurophysiology, Vol. 117, pp. 1376-1379, 2006.

[19] Figure 1 Courtesy of Young, Bryan, Viertio-Oja, Hanna and Sarkela, Mika, “CEEG Monitoring in the ICU: a Systematic Approach, Slide 13, July 11, 2008.