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Ambulatory EEG: a cost-effective alternative to inpatient video-EEG in adult patients

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ABSTRACT – *Introduction*. Ambulatory electroencephalography (AEEG) is a monitoring technique that allows the recording of continuous EEG activity when patients are at home, without the necessity of admission to the hospital for prolonged video-EEG monitoring. *Methods*. This is a prospective cohort study performed in a Canadian academic centre in order to assess the yield and tolerability of AEEG in the adult population. Over a period of three years, 101 patients were included. The yield of AEEG was assessed by taking into account the questions asked by the clinician before and after the investigation. *Results*. One hundred and one patients undergoing AEEG were prospectively recruited during a three-year-period. Our population consisted of 45 males (44.6%) and 56 females (55.4%). The mean age of the group was 36.6±16.1 years. Most of the patients had at least one previous routine EEG (93%). The primary reasons for the AEEGs were subdivided into four categories: a) to differentiate between seizures and non-epileptic events; b) to determine the frequency of seizures and epileptiform discharges; c) to characterize seizure type or localization; and d) to potentially diagnose epilepsy. The mean duration of AEEG recording was 32±17 hours (15-96 hours). For 73 (72%) patients, the AEEG provided information that was useful for the management. For 28 (28%) patients, the AEEG did not provide information on diagnosis because no events or epileptiform activity occurred. In only 1 patient was the AEEG inconclusive due to non-physiological artefacts. Three patients were referred for epilepsy surgery without the necessity of video-EEG telemetry. *Conclusion*. In this study, we found that AEEG has a high diagnostic yield (72%) and believe that careful selection of patients is the most important factor for a high diagnostic yield. The main use of AEEG is the characterization of patients with non-epileptic events, in patients with a diagnosis of epilepsy that is not clear, and quantification of spikes and seizures to improve the medical management. Ambulatory EEG is a cost-effective solution for increasing demands for in-hospital video-EEG monitoring of adult patients.

Key words: ambulatory EEG, portable EEG, epilepsy, non-epileptic events, pseudoseizures, diagnostic yield, cost-of-illness

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Inpatient video-electroencephalography (VEEG) monitoring is the gold standard for diagnostic classification (*i.e.* epileptic *versus* non-epileptic spells) and evaluation of surgical candidates with medically refractory partial seizure disorder for possible focal cortical resections. Although VEEG is the gold standard, it has some disadvantages including the inherent cost of the study and the need for special resources, personnel, and hospitalization (Blume, 1986; Cascino, 2002).

Ambulatory electroencephalography (AEEG) monitoring is a relatively recent technology that allows prolonged electroencephalographic (EEG) recordings in a normal environment. The advantageous feature of the system is the ability to record continuously for up to 96 hours which increases the chances of recording an ictal event or interictal epileptiform discharges. Advances in computer technology offer increased capabilities for AEEG monitoring (Schomer, 2006). The technical specifications of currently available AEEG systems are comparable to inpatient EEG equipment. Because AEEG can be used in outpatient settings and requires only one technologist to apply the electrodes and upload the information, the AEEG appears to be the best resource in a high-load epilepsy clinic. Also, the costs are 51-65% lower than for 24-hour inpatient admission for VEEG monitoring. However, the major appeal of this system appears to be the possibility of recording clinical spells, thereby correlating clinical symptoms with neurophysiological abnormalities (Waterhouse, 2003).

In paediatric populations, the AEEG has contributed to the clinical diagnosis in 31-84% of cases (Foley *et al.,* 1995; Saravanan *et al.,* 2001; Wirrell *et al.,* 2008). We performed a prospective study in the adult population in order to determine the clinical situations in which the AEEG would be most or least helpful, including the reasons for its failure to provide clinically helpful information. Finally, we assessed patient satisfaction of AEEG monitoring.

Methods

Subjects

This study was a prospective cohort study consisting of only adults who were referred for AEEG to the Clinical Neurophysiology Laboratory of the Royal University Hospital (RUH) from 2008 to 2011. RUH is the regional referral centre for the province of Saskatchewan, Canada with a population of one million people. The decision to perform AEEGs is restricted to adult and paediatric neurologists. While no stringent indication exists, an AEEG is performed as an alternative to inpatient video-EEG monitoring if the epileptic nature of the spell is in question; in order to determine the frequency of seizures or interictal discharges, characterize seizure type, or determine candidacy for epilepsy surgery, as well as localize the epileptic focus in candidates for surgery. Prospective subjects were informed of the study at the time of their AEEG appointment and written consent was obtained for participation in the study.

Ambulatory EEG

The AEEGs were recorded using 24 AC channels with 4 differential and 4 auxiliary DC channels capable of continuous recording (XLTEK Trex Ambulatory System). EEG 10-mm diameter, gold-plated cup electrodes with a 2-mm centre hole were attached to the scalp with collodion, according to the International 10-20 System. The patient's head was wrapped with Conform netting for burns to decrease artefact and ensure that electrode placement was secure. An "event" button was attached to the system permitting an indicator of the patient's event which was marked on the EEG recording at the specific time of pressing the event button. The patients were instructed to press the event button for all their events including any auras or spells. Patients and family members documented events with a written diary, detailing the specific time, clinical description, and duration of each event. Antiepileptic medications were not modified prior to the AEEG. The range of usual recording time was between 24 and 72 hours, depending on the frequency of the clinical events and indication of the study. The XLTEK system uses 32 channels and a sampling rate of 512 Hz with storage capacity of 96 hours of recording, including the option of pulse oximetry. The continuous data was uploaded into the specific patient file using the XLTEK database and archived for review and EEG interpretation. The data review was performed by registered EEG technicians and included all the events indicated by patients, the entire recording (to identify interictal EEG abnormalities), and the events indicated by the XLTEK software. The final interpretation was performed by registered electroencephalographers.

Chart review

Neurology clinic charts were reviewed for: demographic data, type and frequency of clinical events, current and previous AED use, previous admissions to the intensive care unit or visits to emergency room, results of image studies, and number of EEGs performed before investigation with AEEG. The information collected from the AEEG included: duration of recording, number and type of clinical events (definite seizures, non-epileptic events, others), complications during AEEG, and type and location of epileptiform discharges.

Physician questionnaires

Referring neurologists were asked to complete a brief questionnaire prior to the AEEG, to determine:
a) the primary and secondary (if any) questions to be addressed by the AEEG;
b) the "most likely" provisional diagnosis (epilepsy, non-epileptic events, others).

Satisfaction questionnaire

To evaluate satisfaction, we asked the patient to complete the 8-item Client Satisfaction Questionnaire (CSQ-8). This scale assesses global satisfaction of groups of service recipients across a broad range of behavioural health and primary care services. It has good reliability and construct validity (Attkisson and Greenfield, 1996; Attkisson and Greenfield, 2005; Larsen *et al*., 1979). The items are phrased as questions and are answered on a 1 (*low satisfaction*) to 4 (*high satisfaction*) merit, with labels specific to particular items. Sample items are: "*How satisfied are you with the amount of help you have received?*" and "*If you were to seek help again, would you come back to our program?*" The overall CSQ scale score was obtained by averaging the items answered with a requirement of at least six of the eight questions answered.

Data Analysis

The diagnostic yield of the AEEG was determined for each of the three primary reasons for performing the study.

Differentiation of seizures from non-epileptic events
For subjects falling into this category, a positive result was defined as a typical recorded "spell", for which the electroencephalographer was able to state "is" or "is not" a seizure. A negative result was defined as either having no events recorded, or having events recorded that could not be accurately identified as seizure *versus* non-seizure, due to possible artefact or other reasons. Subjects with recorded events suggestive of simple partial seizures or seizures originating from the supplementary motor area, orbitofrontal region or cingulate seizures, but who showed no EEG change with these, were also considered to have negative results, given that these seizure types are known to lack scalp EEG correlate in a high percentage of cases. The proportion of subjects with positive results was described as a percentage.

Determination of the frequency of seizures and epileptiform discharges
For subjects falling into this category, a positive result was defined when it was possible to quantify the number of seizures or the amount of epileptiform activity using AEEG. The main purpose of this indication was potential modification of treatment in patients reporting a high frequency of spells.

Characterization of seizure type or localization
For subjects falling into this category, a positive result was defined when it was possible to record seizures by AEEG and the localization of the epileptogenic focus was adequate.

Potential diagnosis of epilepsy
For subjects falling into this category, a positive result was defined as showing clear epileptiform activity in patients with undiagnosed spells, but suggestive of seizures and previous normal routine EEGs. A negative result was defined as not having epileptiform activity.

Secondary analysis

To assess the satisfaction of AEEG monitoring, the mean (SD, range) satisfaction score on the CSQ-8 was reported. The main reasons why it was not possible to address the principal clinical issue using AEEG were described. All analyses were performed using SPSS version 19.0 statistical software (SPSS, Chicago, IL, USA).

Results

General description of the cohort

Between 2008 and 2011, 101 adult patients underwent an AEEG study at the Clinical Neurophysiology Laboratory at the Royal University Hospital, Saskatchewan, Canada. Demographic and clinical data of the subjects are shown in *table 1*. Eighty-seven patients (86%) had 24 hours of recording, 8 (8%) 48 hours and 3 (6%) 72 hours. No complications were reported. The mean duration of recording with AEEG was 32+17 hours (15-96 hours). Thirty-six patients (36%) had previous admissions to the emergency room and 3 (3%) in the ICU over the last year, related to the reason of the investigation with AEEG. Ninety-four patients (93%) had at least one previous routine EEG before the investigation. The number of normal and abnormal EEGs in the group is also displayed in *table 1*. Seventy-six patients (75%) reported between 1 and 10 spells (that could be seizures or non-epileptic events) per month, 10 (10%) between 10 and 20 spells per month, 3 (5%) between 20 and 30 spells, 1 (1%) between 30 and 40 spells, and 11 (11%) between 40 and 200 spells. Fifty-seven percent of patients were on antiepileptic drugs (AEDs) at the time of their AEEG, with an average of 0.9+1.0 medications (0-4). The indications of the AEEG are displayed in *table 2*.

Table 1. Demographic data of subjects (*n*=101).

Gender	
Male	45 (44.6%)
Female	56 (55.4%)
Mean age in years (mean±SD [range])	36.6±16.1 [13-60]
Years of evolution (mean±SD [range])	10.9+14.7 [0-69]
Number of AEDs before test (mean±SD [range])	0.94±1.0 [0-4]
Number of spells per month (mean±SD [range])	14.8±32.8 [1-150]
Number of previous EEGs (mean±SD [range])	2.2±1.6 [1-10]
Number of previous normal EEGs (mean±SD [range])	1.0±1.6 [1-10]
Number of previous abnormal EEGs (mean±SD [range])	1.1±1.2 [0-7]

Diagnostic yield of AEEG

In 73 (72%) patients, the AEEG provided information that contributed to patient management. In 28 (28%) patients, the AEEG was not useful for diagnosis because no events or epileptiform activity were recorded. In only 1 patient, the AEEG was not useful due to artefacts. Of the 28 patients in whom the AEEG was not useful for diagnosis, 12 were referred for future video-EEG telemetry investigation. The categories for cases in which the AEEG was useful are displayed in *table 3*. The information is simplified into the following categories:

a) *Diagnosis of non-epileptic events*. From the 101 patients, 31 (31%) were diagnosed with non-epileptic events. All these patients had typical spells during the recording without epileptiform activity and no interictal findings. In all the patients, the information was useful to manage the patients;

b) *Corroboration of diagnosis of epilepsy*. Fifteen patients were diagnosed with epilepsy with the aid of AEEG. All had spells that were consistent with seizures, although without clear diagnosis, and all had previously normal routine EEGs. All had spikes recorded during the AEEG investigation. All of these patients were started on anti-seizure medications after the test;

c) *Adequate quantification of spikes or events*. In 10 patients, the main issue was the quantification of spikes and seizures with the purpose of potential modification of AED dosage or change of medications. All the patients had generalized or focal epilepsy with a high frequency of seizures. The AEEG was helpful to modify treatment for all of the patients;

d) *No epilepsy surgery due to generalized epilepsy*. Three patients with an established diagnosis of intractable epilepsy, but with no clear determination of seizure onset (normal routine EEGs or very infrequent abnormalities) were investigated by AEEG to explore candidacy for epilepsy surgery. Initially, there was a possibility of focal epilepsy based on clinical description, but in the end all 3 patients were shown to have generalized spike-wave discharges on AEEG;

e) *Potential candidates for epilepsy surgery with focal epilepsy*. Three patients with an established diagnosis of intractable epilepsy, but with no clear determination of seizure onset (normal routine EEGs or no clear abnormalities), were investigated by AEEG to explore candidacy for epilepsy surgery. These 3 patients showed evidence of focal epileptiform activity on EEG and were referred for inpatient video-EEG telemetry;

f) *Potential candidates for surgery with no video-EEG telemetry*. In 3 patients, the possibility of epilepsy

Table 2. Indications for AEEG (*n*=101).

Indication for AEEG	**No. of patients**	**Percentage**
Characterization of spells (query non-epileptic events)	37	36.6
Characterization of spells or spikes (high suspicion of epilepsy)	42	41.6
Quantification of spikes and seizures	10	9.9
Epilepsy surgery workup candidate	9	8.9
Characterization of spells or spikes in patients with epilepsy (potential candidate for epilepsy surgery)	3	3
Total	**101**	**100**

Table 3. Clinical conclusion of the study (*n*=101).

Clinical conclusion after AEEG	Frequency	Percentage
Non-epileptic events	31	30.8
No diagnosis	29	28.9
Corroboration of diagnosis of epilepsy	15	14.9
Adequate quantification of spikes and seizures	10	9.9
Useful to make some clinical decisions	6	5.9
Potential candidate for surgery with no video-EEG telemetry	3	2.9
Not candidate for epilepsy surgery due to generalized epilepsy	3	2.9
Potential candidate for epilepsy surgery with focal epilepsy, requiring video-EEG	3	2.9
Epileptic plus non-epileptic events	1	0.9
Total	**101**	**100**

surgery was considered with the aid of AEEG. One patient had 14 seizures in three days of recording arising from the right temporal region with right mesial temporal sclerosis on the same side. A right temporal resection was performed; the patient has remained seizure-free after a follow-up of 10 months. The second patient had Lennox Gastaut syndrome and the main type of seizure was drop attacks. These were recorded during the investigation and a callosotomy was recommended. The patient was free of drop attacks after surgery. The third patient had seizures arising from the right temporal region where a tumour was present. The surgery was performed after the AEEG;

g) *Epileptic plus non-epileptic events*. One patient had an established diagnosis of epilepsy. The AEEG investigation showed both types of spells (epileptic and non-epileptic spells), although the most frequent were non-epileptic, the findings were therefore helpful for the management of the patient;

h) *Useful for making some clinical decisions*. In 6 patients, the decision as to whether to discontinue antiepileptic medications was made based on AEEG. All of these patients had a single unprovoked seizure and had been started on medication with a plan to discontinue AED treatment. In all, the AEEG which was negative for epileptiform activity was helpful in making the decision to discontinue medications.

Number of spells recorded during investigations

Forty-one patients had spells during the investigation. The mean number of seizures recoded during the AEEG was 26±39 (1-100). The mean number of non-epileptic events was 5.4±8.2 (1-40).

Satisfaction and tolerability of the AEEG

The CSQ-8 was completed in 44 cases. Overall, satisfaction with the procedure was high. The scores of the specific questions are displayed in *table 4*.

Discussion

We found overall that the AEEG contributed to the clinical diagnosis in 71% of patients. In our study, the main utility of the AEEG was to differentiate between seizures and non-epileptic events. In addition, our study showed that AEEG could be used in a broad spectrum of indications with good results in adult patients. The majority of studies evaluating the yield of AEEG have been previously reported in the paediatric population. Saravanan *et al*. (2001) studied 54 children with paroxysmal episodes with AEEG. In 16/31 (52%) children with a recorded typical event, it was possible to determine whether the event was epileptic or not by AEEG. Of these, 10 patients had non-epileptic events. The recording was not considered helpful for the remaining 15 (48%) patients. In the end, the AEEG resulted in an alteration of management in 31% of cases. Olson (2001) assessed the outcomes of 157 children recorded with outpatient AEEG. The authors found that AEEG contributed to the diagnosis in 84% of cases; 140 patients (89%) had clinical events and 107 (76%) of these were non-epileptic. In another study, Foley *et al*. (1995) studied 100 children and adolescents using video-AEEG in an outpatient health centre. Two groups were defined; group I (*n*=64) with preceding epilepsy, where the diagnosis was in question because of ongoing symptoms despite compliance

Table 4. Client satisfaction questionnaire (*n*=44).

Question	Mean+SD
How would you rate the quality?	3.86±0.34
Did you get the kind of service you wanted?	3.59±0.75
To what extent has our program met your needs?	3.49±0.70
Would you recommend our program?	3.68±0.80
How satisfied are you?	3.40±0.87
The service helped you to deal with your problem?	3.37±0.77
How satisfied are you overall?	3.67±0.68
Would you come back?	3.70±0.74

Range between 1 and 4: 1= poor; 4=excellent.

with anticonvulsant medication, and group II (*n*=36) without known epilepsy but with paroxysmal, stereotypic events, and who were investigated in order to confirm or exclude epilepsy. In group I patients, symptomatic events were recorded in 80%, of which just over a half were seizures. Among group II patients, events were recorded in 89% and seizures were reported in 22%. The authors concluded that AEEG with video is a cost-effective, useful alternative to continuous inpatient video-EEG monitoring in the investigation of selected infants, children, and adolescents with diagnosed or suspected epilepsy. Overall, the clinical question was answered in 83% of cases.

While AEEG at home is a useful diagnostic tool, some disadvantages are clearly identified. Certain seizure types, such as simple partial, supplementary motor, cingulate or orbitofrontal seizures may show minimal or no changes on ictal scalp EEG, therefore AEEG would not be a definitive test in order to rule out epilepsy in some cases. For these cases, video-EEG telemetry should be the gold standard for investigation. For AEEG, the significant disadvantage is the lack of video recording; in all cases, the history provided by the patient and the family or caregivers has to be relied on (Cull, 1985). Recording clinical seizures outside of the hospital setting also limits the opportunity for a trained observer to assess ictal or postictal language or motor deficits, which may provide useful clinical information. Artefact recognition could be a limitation of the AEEG, however, both in our study and that of Olson (2001), artefacts did not significantly limit interpretation of the AEEG. Only one study was not useful due to the presence of artefacts. Finally, technical support is not immediately available in the home setting, however, in our study and that of Olson (2001), this was not an issue.

Few studies have assessed the yield of AEEG in adults. Liporace *et al*. (1998) compared the clinical utility of AEEG *versus* sleep-deprived EEG in 46 patients. The authors concluded that the computer-assisted AEEG offers greater benefit than a sleep-deprived recording because, in addition to detecting interictal epileptiform discharges, it may also capture seizures. Tatum *et al*. (2001) reviewed 552 records from 502 patients who underwent outpatient 16-channel computer-assisted AEEG monitoring (CAA-EEG); 47/552 (8.5%) showed seizures during the recording and 11/47 (23.4%) showed seizures recognized only by the computer. The authors concluded that patients frequently have seizures outside the hospital that are unrecognized.

In our experience, AEEG is probably most useful for adult patients with frequent clinical spells, in order to differentiate between epileptic and non-epileptic events. Compared to the paediatric population, the AEEG could be used in different circumstances in the adult population. In our study, the AEEG was very helpful to quantify seizures and epileptiform activity in patients where a modification of management was required. A significant number of patients were diagnosed with epilepsy with the help of the AEEG after months, without clear diagnosis. In all the cases, the AEEG revealed either focal or generalized epileptiform activity which was useful to start treatment in some patients. Several of these patients had a single unprovoked seizure with risk factors for epilepsy and were finally diagnosed with epilepsy. In some patients, the AEEG was useful to explore candidacy for epilepsy surgery. A potential indication could be the investigation of patients with intractable epilepsy where the routine EEGs have shown minimal, unclear onset or no abnormalities. In some patients from our cohort with suspected focal epilepsy, the investigation with

AEEG showed bursts of generalized spike and wave. Therefore, in these cases, AEEG was helpful in avoiding inpatient video-EEG telemetry.

The use of AEEG for epilepsy surgery is not well studied. In our study, AEEG was used to determine surgery candidacy for 3 patients without the necessity of video-EEG telemetry. The potential use for this indication should be explored in the future. According to our results, AEEG could be used in selected cases in order to decide whether to perform epilepsy surgery. From our point of view, a potential case for epilepsy surgery, investigated by AEEG, should meet the following requirements: an adequate number of typical events recorded by AEEG and congruent EEG and MRI findings, and probably only be used for temporal lobe epilepsy cases. We indicated a successful callosotomy in a patient with an established diagnosis of generalized epilepsy and with a significant number of drop attacks recorded by AEEG. This indication, as well as the use of AEEG in extratemporal cases, needs more investigation since only a few reports have been published (Chang *et al*., 2002).

Our study shows that the AEEG in selective cases eliminates the need for inpatient investigations, being a cost-effective intervention. Satisfaction rates measured in our study were very high. In general, the CSQ-8 reflects the overall satisfaction of our comprehensive program, although the tool shows, to some extent, the satisfaction of patients with AEEG. Our high rates of satisfaction are similar to those found in the study of Wirrell *et al*. (2008). While we did not compare our results directly to the gold standard, inpatient video-EEG monitoring, we doubt this would have altered our results as the quality of the EEG recording was good and the semiology of the seizures reported by the families/caregivers was more consistent with seizures associated with EEG changes.

Few studies have compared AEEG to video-EEG telemetry. The only study comparing both techniques was performed by Ebersole and Leroy (1983) who examined the diagnosis based on AEEG alongside inpatient monitoring in 40 children. The accordant diagnosis for normal EEG was 100%, for abnormal non-epileptic EEG 60%, and for abnormal epileptic EEG 54%. Correct lateralization and anterior *versus* posterior localization of epileptiform features occurred in 78% and 72%, respectively. However, in this study, AEEG recordings were performed using only three channels which clearly limited interpretation. A limitation of our study is the reduced sample size for some of the evaluated subgroups. Potential indications of AEEG, such as the inclusion of AEEG as part of the workup for epilepsy surgery or use to guide management of drugs, needs further investigation with larger sample sizes.

We conclude that AEEG is a useful diagnostic test in adult patients with epilepsy for various purposes including the assessment of frequency of seizures, diagnosis of suspected epilepsy, and, most importantly, the evaluation of patients with non-epileptic events. Further studies in the adult population, which compare AEEG and video-EEG telemetry in order to characterize the diagnostic efficacy of AEEG for our proposed indications, are needed. We believe that, at present, this technique is underutilized in the adult population. □

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