THE YALE JOURNAL OF BIOLOGY AND MEDICINE 60 (1987), 85-91

Ambulatory Cassette EEG in Epilepsy Diagnosis

JOHN S. EBERSOLE, M.D.

Department of Neurology, Yale University School of Medicine, New Haven, and Epilepsy Center, West Haven VA Medical Center, West Haven, Connecticut

Received May 22, 1986

The electroencephalographic evaluation of patients with possible or proven epilepsy is no longer limited to routine laboratory EEGs or intensive inpatient monitoring. Expanded temporal sampling of the EEG, which increases the probability of documenting, characterizing, and quantitating the electrographic manifestations of these illnesses, is now available on a portable, outpatient, and less cumbersome inpatient basis by means of ambulatory cassette recordings. The technological advances which have made this technique feasible include small multi-channel tape recorders, miniature preamplifiers, and rapid video/audio playback units. New designs in montages and analysis techniques have made the procedure practical. Clinical series and controlled trials have confirmed the usefulness of cassette EEG monitoring in the evaluation of epilepsy and a wide range of other paroxysmal neurologic disorders. Ambulatory EEG diagnostic yields have been shown to be superior to routine laboratory studies and nearly as good as inpatient telemetry evaluations. The role of cassette recordings in clinical electroencephalography continues to be defined as new applications are established.

INTRODUCTION

The relatively short duration of a standard EEG is not well suited to detect paroxysmal abnormalities that are infrequent. Long-term inpatient monitoring is now recognized as the most reliable means available for the diagnosis and clarification of epilepsy. It has, however, inherent disadvantages. Chief among these are that hospitalization is required and patient mobility and activities are restricted. The hospital setting is also clearly unnatural, which may inhibit both epileptic and nonepileptic episodes. Evaluations by long-term monitoring are often unavailable, for only a modest number of centers exist, and those usually have a patient backlog on the order of several months. Finally, intensive inpatient monitoring is, by its very level of sophistication, an increasingly expensive proposition.

Ambulatory EEG monitoring (A/EEG) by cassette tape recorder was commercially introduced in 1979. It seemed to hold great promise in assisting in the differential diagnosis of episodic loss or alteration of consciousness by providing expanded temporal sampling of the EEG and other physiologic parameters on a portable and outpatient as well as an inpatient basis (see [1] for review). Patients did not need to be hospitalized but were free to pursue normal daily activities. Other advantages included a natural home or work setting, with its accompanying normal stress, to evoke the episodes in question. Potential greater availability and reduced cost relative to hospitalization could result in improved and more economical patient care.

AMBULATORY CASSETTE EEG EQUIPMENT

All commercial four-channel recorders are standard analog devices utilizing four recording heads with 1/8 or 1/4 inch tape. Tape speed is reduced to approximately 2 mm

Address reprint requests to: John S. Ebersole, M.D., Dept. of Neurology, Yale University School of Medicine, New Haven, CT 06510

per second so that a standard C120 or a ¼ inch cassette can record at least 24 hours of continuous EEG. Recorders weigh approximately 1.5 pounds and are easily worn on belt or strap by most patients, including small children. Preamplification is accomplished usually in small head-mounted chips, one for each channel, which are fastened to the scalp with collodion, as are the disc electrodes. Paginated rapid video playback was the conceptual breakthrough that made efficient analysis of long-term ambulatory cassette tape recordings feasible. The first playback units incorporated a video display of data at selectable page lengths and speeds of replay, plus a simultaneous audio reproduction of one data channel. At the fastest replay speed, usually sixty times real time, twenty-four hours can be reviewed in twenty-four minutes. Epochs of data displayed on the screen can be written out on paper by connecting the playback unit to a standard EEG machine.

Eight-channel A/EEG systems, introduced in 1983, represent the present-day standard. Two different technologies are used by commercial manufacturers. In one system, a new recording method called "blocked analog" was developed in order to record eight channels of physiologic data plus real digital time and events on standard ⅛ inch tape. The other eight-channel system uses a special ¼ inch cassette tape, which permits eight channels of physiologic data plus time to be recorded in standard analog fashion using a nine-channel recording head. Size of both eight-channel recorders is only slightly larger than the smallest four-channel recorder. Off-head preamplification is now available within the recorder or in small packets worn by the patient.

The new eight-channel playback units provide not only a means of displaying additional physiologic data, but a number of improved operational features. These include: digital real time as a separate channel, automatic search to a specific time, up to 64 seconds of memory so that approximately 30 seconds before and after the present screen can be viewed without tape movement, gain and filter adjustments without tape movement, alphanumeric registry of channel gain and filtering status, continuous printout of data as well as epoch printout, and stereo audio reproduction utilizing any number of component channels.

DURATION OF RECORDING

The logistics of running an outpatient A/EEG laboratory, as well as the technology of the recording, lend themselves to 24-hour recording periods. The tape has to be changed and the batteries replaced every day, if monitoring is to continue for a longer period. In addition, the electrodes should be checked for impedance and rejelled if necessary. In many laboratories the patient returns every 24 hours for this maintenance. Others give the patients extra tapes, batteries, and even syringes filled with electrode paste to rejell the electrodes themselves every day during the recording period.

The diagnostic yield from A/EEG also defines productive recording periods. Several studies have shown that most interictal EEG abnormalities will be present during the first 24 hours of monitoring, particularly during the overnight sleep period [2,3]. Recording beyond this time in search for interictal features is progressively less rewarding, unless the patient's condition changes, such as when anti-epileptic medications are withdrawn in hospital. The likelihood of recording seizures continues to increase over time, however. Usually, limitations are placed for practical reasons at several days of recording. In outpatient clinical practice, most screening A/EEGs of a diagnostic nature are 24 hours long. If no abnormalities are noted, it may only be

TABLE 1
Examples of Ambulatory Cassette EEG Montages

1. Three EEG channels			*2. Four EEG channels*				
T5-F7	T5-T1	P3-F3	T5-T3	T5-T1			
F5-F6[a]	F7-F8[a]	F7-F8[a]	F7-F3[a]	F7-F1[a]			
F8-T6	T2-T6	F4-P4	F4-F8[a]	F2-F8[a]			
			T4-T6	T2-T6			
3. Six EEG channels			*5. Seven EEG channels*			*6. Eight EEG channels*	
T5-T3[a]			T5-T3	F5-C3		T5-T3[a]	F3-C3
T3-F7			T3-F7	T5-T3[a]		T3-F7	T5-T3[a]
F7-F3[a]			F7-F3	T3-F7		F7-F3[a]	T3-F7
F4-F8[a]			F4-F8	F5-F6[a]		F3-C3	F7-F3[a]
F8-T4			F8-T4	F8-T4		C4-F4	F4-F8[a]
T4-T6[a]			T4-T6	T4-T6[a]		F4-F8[a]	F8-T4
			F5-F6[a]	C4-F6		F8-T4	T4-T6[a]
						T4-T6[a]	C4-F4

[a] Audio monitor

worthwhile to continue EEG monitoring if the patient's habitual spells are frequent enough that one is likely to be recorded within another day or two.

A/EEG MONTAGE DESIGN

It is essential that ambulatory EEG montages fulfill two goals. The first is to maximize the likelihood of detecting abnormal EEG features, particularly since channel numbers are limited when compared to laboratory EEG. The second is that the data must be displayed in a form that is conducive to perception of these abnormalities on rapid video playback. In satisfying these dual goals, montage design concepts somewhat different from traditional EEG are commonly employed. Design of three- and four-channel montages is perhaps the most difficult since channel numbers are so restricted. A retrospective review of the distribution of 139 epileptiform abnormalities in 115 adult and adolescent patients with epilepsy verified that focal abnormalities were concentrated in the frontotemporal regions [4]. Preferential sampling of these areas is therefore indicated when the number of channels is limited, particularly since generalized epileptiform features can be detected in montages of nearly any configuration.

If channels are organized into a chain with a left, transverse, right sequence, such as the examples in Table 1, surface negative epileptiform potentials of the frontotemporal regions will appear as phase-reversing transients common to two channels. These phase reversals greatly enhance the perception of an isolated epileptiform event on video playback. Four-channel montages which follow the same pattern provide smaller inter-electrode distances and reduce the possibility of missing a precisely midtemporal or midfrontal abnormality because of voltage cancellation. Arranging the channels in a manner to produce a video display with mirror-image symmetry is also an aid to perceiving lateralized events upon rapid review. Many normal EEG transients, such as vertex sharp waves or K complexes, and most physiologic artifacts, such as eye movement and muscle potentials, produce bilateral and often symmetrical waveforms. The recognition of an asymmetry in the ongoing video EEG pattern during playback, rather than a specific transient, is often the initial step in detecting focal abnormalities. These can then be confirmed on inspection of the static page.

Eight-channel montages that are modifications of the same basic pattern of bitemporal and frontal coverage may be more useful than traditional ones for the same reasons. Examples are listed in Table 1. The increased number of EEG channels provides greater spatial resolution and negates the weaknesses that existed in the three- and four-channel versions in the midtemporal and midfrontal regions. Frontocentral coverage is also improved. Posterior regions remain purposefully neglected, since the incidence of epileptiform abnormalities there is small in adults and adolescents. In young children a modification of these montages to include posterior locations would be indicated.

PRINCIPLES OF RAPID VIDEO/AUDIO REVIEW

The relationships of artifacts, confusing normal transients, and epileptiform abnormalities to normal sleep-wakefulness cycles provide the basis for a useful protocol for reviewing A/EEG tapes. Analysis of A/EEG during active wakefulness should be aimed principally at the detection of seizures. Active wakefulness is filled with eye movement, muscle, and electrode artifacts. Individual epileptiform transients, even if present, are difficult to recognize or differentiate during these periods. The rhythmic and progressive character of a seizure pattern contrasts sufficiently with the irregular background of wakefulness to permit relatively easy detection. The typical evolution of the EEG during a seizure from a low-voltage fast onset to a higher-amplitude slower ending results in a characteristic audio tone burst of declining frequency. This characteristic progression is a key factor in differentiating seizures from confusing rhythmic artifacts. Such artifacts during active wakefulness are, on the contrary, often of non-varying frequency, of non-physiologic distribution, and interrupted in character as compared to the progressive frequency and amplitude changes of a seizure. An appropriate diary entry, post-ictal slowing, and interictal features in other portions of the record provide support for seizure identification. A scanning speed of 60 times real time can be realistically used to detect seizures both visually and by sound.

Eye movement, muscle, and electrode artifacts diminish during quiet wakefulness and essentially cease during stages of slow-wave sleep. On the other hand, epileptiform abnormalities increase in frequency or may be only apparent during stages one through three of sleep [2,3]. These two opposing relationships make light sleep the most reliable and productive period of time to identify interictal epileptiform abnormalities. A 20-times real-time scanning speed provides more opportunity for the recognition of these individual transients.

INDICATIONS FOR AMBULATORY CASSETTE EEG

The following is an outline of recommended clinical indications for ambulatory EEG monitoring. This listing is not meant to be all-inclusive, since special circumstances may warrant additional considerations.

Diagnosis

1. Documentation of clinically suspected, paroxysmal electrographic abnormalities in patients with normal or equivocal routine EEG studies: These include seizures, overt and subclinical, and interictal epileptiform discharges.

EEG abnormalities which are identified may assist in the differential diagnosis of seizure disorder from syncope, cardiac arrhythmias, transient ischemic attacks,

narcolepsy, other sleep disturbances, psychogenic seizures, or other behavioral disorders.

2. Verification of the ictal nature of new "spells" in a patient with previously documented and controlled seizures

3. Documentation of clinically suspected, non-EEG, paroxysmal electrographic abnormalities: These include cardiac arrhythmias via ECG, abnormalities of sleep or sleep-related respiration via EEG, EMG, EOG, ECG, and/or respiration parameters.

Classification/Characterization

1. Electrographic classification of seizure type(s) in a patient with documented but poorly characterized epilepsy

2. Characterization (lateralization, localization, distribution) of EEG abnormalities, both ictal and interictal, associated with seizure disorders

The extent of characterization is dependent upon the number of EEG channels available: Lateralization, but not localization, is possible with four-channel ambulatory EEG systems.

3. Characterization of the relationship of seizures to specific precipitating circumstances or stimuli (e.g., nocturnal, catamenial, situation-related, activity-related); verification and/or characterization of periodic seizure patterns

Quantification

1. Quantification of the number or frequency of seizures and/or interictal discharges and their relationship to naturally occurring events or cycles

2. Quantitative documentation of the EEG response (ictal and interictal) to a therapeutic intervention or modification (e.g., drug alteration)

Monitoring objective EEG features is most useful in patients with frequent seizures and/or interictal discharges, and particularly with absence and other seizures having indiscernible or minimal behavioral manifestations.

DIAGNOSTIC YIELDS

Although there was initially concern over the usefulness of A/EEG data when restricted to three or four channels, controlled studies comparing this to sixteen-channel baseline recordings and eight- to sixteen-channel cable telemetry showed a respectable relative yield (77 and 93 percent) in the identification of epileptiform abnormalities [5,6]. Detection of seizures was 100 percent for those both generalized and focal, and false-positive errors were at an acceptable level. The ability of the electroencephalographer to differentiate abnormalities from artifacts and normal transients on rapid video review was found to be a greater limiting factor than the restricted number of data channels [7,8]. This finding was confirmed in a recent comparison of three- and eight-channel ambulatory EEG systems, which showed nearly comparable yield in the detection of both ictal and interictal EEG features [9]. Only in detailed characterization of epileptiform events were eight channels shown to be superior to three. Eight-channel recordings clearly had an advantage in differentiating true abnormalities from artifacts, however, and in so doing yielded a reduced

number of false-positive errors. In these same studies, ambulatory EEG monitoring was shown conclusively to be superior to routine baseline recordings. Identification of epileptiform abnormalities, both interictal and ictal, was increased by ambulatory EEG over routine EEG by a factor of 1.5 to 2.5 [5,6].

In an analysis of clinical usefulness relative to the referral questions, twenty-four hours of ambulatory EEG was found to provide as much positive or negative information as did intensive inpatient monitoring (average, 4.4 days) in 60 percent of diagnostic admissions. The greatest advantage of intensive inpatient monitoring over ambulatory EEG was not its electroencephalographic superiority, but the additional information obtained through video monitoring of behavior and the ability to withdraw anti-epileptic medications under medical observation [6]. Ambulatory EEG recordings need not, however, be limited to twenty-four hours or to outpatients. Their use in an inpatient or monitored outpatient setting coupled with the capability to do video recording and perhaps selective drug withdrawal could make this form of recording nearly comparable to present-day intensive monitoring.

Ambulatory cassette EEG is like any other diagnostic test, however. Its utility in general practice is dependent upon the appropriateness of the questions asked. A number of clinical series using unselected referrals have shown similar results: a positive yield increase of 10 percent in electrographic abnormalities [10] and significant positive findings in 11 percent of patients [11]. We have recently reviewed our experience with 500 consecutive patients, age two months to 82 years, referred for A/EEG [12]. Seizures, interictal epileptiform abnormalities, or both were detected in 87 of the tapes, or 17.4 percent. Notable was the fact that 22 of these patients, including nine in whom EEG seizures were recorded, were thought probably not to have epilepsy and were not receiving anticonvulsant medication at the time. Nearly half of the patients had had a routine EEG at our laboratory. Among these, there was a 64 percent increase in the yield of interictal epileptiform abnormalities and a 21-fold increase in seizure recording with A/EEG. Failure to detect epileptiform abnormalities on A/EEG after their demonstration on routine EEG was seen in a few patients with photoconvulsive responses or when anticonvulsant medication was started between the two studies.

These overall yields include patients referred for many reasons. When analyzed by specific clinical problems or by the perception of the physician, definite trends emerge. We found a particularly high yield (34.9 percent) in those patients whose requests included an affirmative statement regarding epilepsy as the diagnosis. Positive yield was 15.3 percent in patients referred with a wide variety of episodic alterations of behavior, perception, sensation, or motor function thought possibly to represent seizures. On the contrary, the yield was very low (1.5 percent) in patients referred for probable syncope or related complaints. Among patients whose clinical problem lacked definite paroxysmal features, consisting primarily of children with developmental delay and adults with a variety of psychiatric disorders, none had A/EEG evidence of epilepsy. These results underscore the need for reasoned clinical judgment in the application of A/EEG.

REFERENCES

1. Ebersole JS: Ambulatory cassette EEG. J Clinical Neurophysiology 2(4):397–418, 1985
2. Delgado-Escueta AV: Epileptogenic paroxysms: modern approaches and clinical correlations. Neurology 29:1014–1022, 1979

3. Ebersole JS, Spencer SS: The efficacy of 24-hour EEG monitoring in epilepsy diagnosis. Epilepsia 22:235–236, 1981
4. Leroy RF, Ebersole JS: An evaluation of ambulatory cassette EEG monitoring: I. Montage design. Neurology 33:1–7, 1983
5. Ebersole JS, Leory RF: Evaluation of ambulatory cassette EEG monitoring: III. Diagnostic accuracy compared to intensive inpatient EEG monitoring. Neurology 33:853–860, 1983
6. Bridgers SL, Ebersole JS: The clinical utility of ambulatory cassette EEG. Neurology 35:166–173, 1985
7. Ebersole JS, Leory RF: An evaluation of ambulatory, cassette EEG monitoring: II. Detection of interictal abnormalities. Neurology 33:8–18, 1983
8. Ebersole JS, Bridgers SL, Silva CG: Differentiation of epileptiform abnormalities from normal transients and artifacts on ambulatory cassette EEG. Am J EEG Technol 23:113–125, 1983
9. Ebersole JS, Bridgers SL: A direct comparison of 3 and 8 channel ambulatory cassette EEG with intensive inpatient monitoring. Neurology 35:846–854, 1985
10. Green J, Scales D, Nealis J, Scott G, Driber T: Clinical utility of ambulatory EEG monitoring. Clinical EEG 11:173–179, 1980
11. Ramsay RE: Clinical usefulness of ambulatory EEG monitoring of the neurological patient. In ISAM 1981: Proceedings of the Fourth International Symposium on Ambulatory Monitoring. Edited by FD Stott, SL Wright, EB Raftery, DL Clement. London, Academic Press, 1982, pp 234–243
12. Bridgers SL, Ebersole JS: Ambulatory cassette EEG in clinical practice. Neurology 35:1767–1768, 1985