Scalp-Recorded Ictal Patterns in Focal Epilepsy

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Summary: Scalp-recorded focal EEG seizure patterns are usually expressed as rhythmic metamorphic evolving patterns (with or without epileptiform morphology) that progress through two or more ictal phases into a postictal change. Such patterns are almost invariably seen in temporal complex partial seizures but less often detected in frontal complex partial seizures and least of all in simple partial seizures. The failure of scalp recordings to detect activity from a focal seizure can usually be explained by the seizure's distant location, limited extent, or disadvantageous orientation with respect to scalp electrodes. The elimination of these disadvantages with properly implanted electrodes explains why these recordings are able to detect seizure discharges missed by scalp electrodes. Although the lateralization of a scalp-recorded seizure can be misleading, it usually accurately identifies the focus when it remains well-lateralized throughout its various ictal phases and into the postictal state.

Key Words: Epilepsy—Seizures—Ictal patterns—Scalp electrodes.

Focal epileptic seizures are clinical episodes due to an electrographic seizure discharge localized to a part or region of the brain. In principle, the electrical discharge associated with any epileptic seizure can be recorded provided the electrodes are placed sufficiently close to the discharging region. However, in practice, especially with minor nonamnestic simple partial seizures without impairment of consciousness, the discharge may be localized and distant enough from scalp electrodes that such seizures may occur in absence of a scalp-recorded EEG accompaniment (Devinsky et al., 1988, 1989). Therefore, the occurrence of these episodes without a scalp-detectable EEG change never excludes the possibility that they are epileptic seizures. On the other hand, amnestic seizures with significant impairment of responsiveness almost always occur in association with an identifiable EEG change (Klass, 1975).

In addition to not being able to identify scalp-recorded EEG changes with subtle nonamnestic epileptic seizures, it is sometimes difficult to determine whether certain EEG patterns accompanying clinical episodes represent electrographic seizure activity (in which case, the episode is to be considered an epileptic seizure) or some other activity (in which case, the episode is to be considered a nonepileptic seizure). The type of activity that may at times be difficult to distinguish from electrographic seizure discharges includes abundant interictal epileptiform activity or even nonepileptogenic abnormal or normal rhythmic activity.

The above difficulty in determining whether or not an EEG pattern represents an electrographic seizure most commonly occurs in the following two electroclinical situations: (1) short-lasting patterns accompanying a brief episode occurring at the time of a dramatic state change, such as transition from sleep to wake or from deeper to lighter coma, and (2) long-lasting patterns associated with extended episodes of altered consciousness.
An intelligent approach to trying to resolve some of the above problems requires a clear definition of the various types of electrographic seizure patterns framed in the context of all other potentially epileptogenic patterns, which include both interictal (epileptiform) patterns as well as ictal (electrographic seizure) patterns. Unfortunately, the definitions of all these patterns have to be fitted into a probabilistic rather than a deterministic framework. With these limitations in mind, the following definitions of these patterns will be used in this article.

DEFINITIONS

Epileptogenic Patterns

An EEG pattern, whether commonly seen in the interictal (epileptiform) or ictal (electrographic seizure) state, occurs with a significantly greater frequency in patients experiencing epileptic seizures than in other patients, and even less frequently in normal controls. This definition suggests that "potentially" epileptogenic patterns can be considered as an EEG risk factor for clinical epileptic seizures, but their absence in a recording does not exclude, and further, their presence does not assure, the diagnosis of epilepsy.

Epileptiform Interictal Patterns

This is a potentially epileptogenic pattern, which is commonly interictal and includes spikes and sharp waves, alone or accompanied by slow waves occurring singly or in bursts, lasting at most a few seconds.

Electrographic Seizure Patterns

This is a potentially epileptogenic pattern, which is commonly associated with a clinical seizure, lasting for more than several seconds and consisting of rhythmic repetition of components that may or may not have an epileptiform morphology and may or may not progress through two or more ictal phases into a postictal state. Different ictal phases, if present, are differentiated based on characteristic component morphology, frequency, topography, and amplitude. When a true electrographic seizure pattern does not produce clinical symptoms, it is called a subclinical electrographic seizure discharge. Others (Kooi, 1971; Niedermeyer, 1982) have recognized the presence of two major types of electrographic seizure patterns, as follows.

Isomorphic Seizure Pattern

The isomorphic seizure pattern ends as it begins, without progressing through multiple phases into a postictal state. Further, the ictal morphology not only remains isomorphic throughout the seizure but is usually isomorphic or similar to interictal epileptiform patterns from which it may differ only in having greater rhythmicity, duration, spatial extent, and amplitude.

The isomorphic seizure pattern is almost exclusively seen in generalized seizures and is clinically represented by the generalized 3/5 spike-and-wave pattern seen in typical absence seizures. Experimentally, this corresponds to what has been designated as first-degree epileptogenicity by Gloor (1979). This pattern is mentioned for completeness, but since it is almost never seen as the only manifestation of a focal seizure discharge, it will not be discussed further in this article.

Metamorphic Seizure Pattern

The metamorphic seizure pattern, on the other hand, usually ends quite differently from its beginning, commonly progressing through two or more recognizably different ictal phases into a postictal state. Not only can the ictal morphology during one ictal time segment be metamorphic or dissimilar to activity during other ictal time segments, but it can also be strikingly dissimilar to interictal epileptiform spikes or sharp waves. In fact, in certain cases, ictal morphology may consist of smooth sinusoidal rhythms (Klass, 1975; Blume et al., 1984), which morphologically not only may contain no epileptiform spikes or sharp waves but rather closely resemble normal rhythmic background. Such seizure discharges can be differentiated from normal background not by morphology or frequency but only in the context of progression and spatial extent.

The metamorphic seizure pattern is seen both in generalized seizures (i.e., generalized tonic-clonic seizures, infantile spasm, tonic seizures, and others) and focal seizures (Kooi, 1971). Experimentally, it corresponds to second-degree epileptogenicity as defined by Gloor (1979).

It should be emphasized, as has already been pointed out by others, that the above definitions, as well as the official definitions from which they were derived (Chatrian et al., 1983), serve mainly as useful guides for teaching others how to recognize these patterns. However, they are far too ambiguous to enable the novice to easily recognize the patterns.
without consultation with an experienced teacher or to allow a programmer to reliably design a computer system for recognizing the patterns. In spite of these drawbacks, it is instructive to look at which aspects of the definitions are incorporated into the current programs for computer recognition of the two different ictal patterns. Programs take advantage of the fact the isomorphic patterns usually have a higher amplitude, a fixed rhythmicity, and a mixture of "spikes" and slow waves (Frost, 1985). On the other hand, recognition of metamorphic seizure discharges cannot depend solely on the detection of the epileptiform patterns because, as mentioned, epileptiform morphology may not be present during the course of the seizure discharge. Therefore, one technique that has been applied extensively in the clinical setting relies on the fact that at least during some phases, many metamorphic seizure discharges show a relatively sustained (lasting more than 2 s) rhythmic activity with frequencies between 3 and 20 Hz, in which the amplitude is significantly greater than the preceding background (Gotman, 1985). Because it was recognized that this detection of algorithm misses low amplitude and usually faster frequency seizure discharges, another selection criterion is sometimes added. This criterion identifies as a possible electrographic seizure any sustained (lasting more than 2 s) rhythmic faster (60% faster than background) pattern, even though it is not of higher amplitude than the background (Gotman, 1985). Although this approach is not perfect because it misses some electrographic seizures easily identified by a reader and includes a number of EEG changes related to non-epileptic state changes (the latter can be excluded on visual inspection by the electroencephalographer), it nonetheless emphasizes some of the more important points the reader has to take into consideration when trying to identify the various seizure patterns.

Since focal seizures demonstrate metamorphic seizure patterns almost exclusively, the following sections will review scalp-recorded metamorphic seizure patterns seen during simple partial seizures and then complex partial seizures, first of temporal and then of extratemporal origin.

**SIMPLE PARTIAL SEIZURES**

As mentioned above, simple partial seizures frequently occur without a scalp-detectable seizure discharge (Devinsky et al., 1988, 1989). This is true whether the simple partial seizure is the total seizure or the aura preceding the complex phase of a seizure and whether the seizure is of temporal or extratemporal origin.

Since the inability to record a scalp discharge during a simple partial seizure is often due to the fact that the discharge is too localized and distant from the scalp, it is understandable that the incidence of recorded discharges increases significantly when implanted electrodes are used (Leib et al., 1976; Devinsky et al., 1988, 1989).

Even when no obvious scalp discharge is detectable, there may be local or generalized attenuation of interictal activity including epileptiform discharges during the seizure (Gastaut and Broughton, 1972; Quesney and Gloor, 1985; Engel, 1989). When a seizure discharge is detected during a simple partial seizure, its nature is similar to that seen during a complex partial seizure, as will be discussed in the next section.

**TEMPORAL COMPLEX PARTIAL SEIZURES**

Whether a temporal lobe seizure begins with an aura or with impairment of consciousness, it is common for interictal spikes, as well as the more normal interictal background pattern to be attenuated (Ralston and Papadieodorou, 1960; Geiger and Harner, 1978). When this occurs in a clear focal manner, it is an extremely reliable localizing feature even though it is not immediately accompanied by a scalp-identifiable rhythmic seizure discharge (Figs. 1 and 2).

Although a rhythmic scalp-recorded seizure discharge may not be seen during the simple phase or even at the onset of the complex phase of a temporal seizure, such a discharge is almost invariably detected in a later time segment during the evolution of the complex seizure. In fact, in two separate studies, all patients with scalp-recorded partial seizures showed changes during the complex phase of the seizure (Klass, 1975; Delgado-Escueta and Walsh, 1985). In addition to attenuation of the interictal pattern either in a focal or more generalized manner, evolving rhythmic discharges (with or without identifiable epileptiform components) occur, which, although usually more prominent in one temporal lobe, are nonetheless commonly reflected bilaterally in the scalp EEG (Fig. 3).

In one study (Klass et al., 1973) of EEG recordings during 116 partial seizures (a mixture of simple and complex seizures), the initial manifestations were only attenuation in 25%, a rhythmic seizure discharge
SCALP-RECORDED FOCAL EEG SEIZURE PATTERNS

Age: 26 yr
A1-T3
T3-C3
C3-Cz
Cz-C4
C4-T4
T4-A1

(continued)

FIG. 1. The electrographic onset of this patient's left temporal lobe seizure was characterized by an attenuation of the continuous, repetitive, focal interictal spike-and-slow-wave pattern. During this initial phase of attenuation, no scalp-recognizable electrographic discharge was noted for a number of seconds until a 6-7-Hz theta-range metamorphic seizure discharge became visible in the left temporal area. This increased in frequency and became bilateral as the patient developed impairment of consciousness.

At this point, it is instructive to contrast temporal lobe scalp-recorded metamorphic seizure patterns to the same seizure patterns recorded with implanted electrodes where classic description is as follows: Most focal seizures begin with a low-voltage fast beta range discharge (Gloor, 1975) and progress to higher voltage and lower frequency as the attacks proceed (Sypert et al., 1970). Further, implanted electrodes frequently detect seizure activity during a simple partial aura (Devinsky et al., 1989) and at the onset of complex partial seizures.

Scalp-recorded temporal lobe seizures differ from the implanted electrode recordings in three important ways. First, a seizure discharge during a simple partial aura is detected much less often with scalp than with implanted electrodes. In two studies (Devinsky et al., 1988, 1989), these detection rates were approximately 20% versus 90%. Further, even though scalp recordings almost invariably detect a temporal lobe seizure discharges (Blume et al., 1983), the initial electrographic manifestation was only attenuation in 10%, rhythmic seizure discharge without epileptiform morphological features in 43%, and rhythmic seizure discharge with epileptiform components (spikes or sharp waves) in 41%.

FIG. 2. The metamorphic seizure discharge that originally began in the 4-Hz range (Fig. 2) increased in frequency to the 7-Hz range as the seizure evolved. Before finally progressing into a secondary generalized convulsion (last two sections of the figure), the seizure discharge developed a mixed frequency including a 3-Hz delta intermixed with an alpha-beta-range seizure discharge that ultimately became obscured by muscle at the beginning of the convulsive generalization.

Without epileptiform morphological features in 14%, and repetitive epileptiform discharges in 30%. No EEG change was detected at the onset of clinical symptoms in 10%. However, in this study, no complex partial seizure, as currently defined, failed to demonstrate an EEG change throughout the entire attack. In a more recent study of 66 scalp-recorded

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discharge during the complex phase, the detection may not occur at onset as it usually does with implanted electrodes.

Second, the frequency of the initial scalp-detected rhythmic seizure discharge is commonly in the alpha, theta, or even delta range (Gotman et al., 1980; Blume et al., 1984; Risinger et al., 1989; Walczak et al., 1992) rather than the beta range as it is in implanted electrode-recorded seizures (Figs. 1 and 2).

Third, during the earlier metamorphic phases of a scalp-recorded temporal lobe seizure, the frequency of the discharge is as likely to increase (Figs. 2 and 3) as decrease (Fig. 4) (Anziska and Cracco, 1977; Blume et al., 1984). In fact, in scalp-recorded temporal complex partial seizures, it is only during the final ictal time segment that the frequency almost always becomes slower than it was during at least one earlier ictal time segment (Blume et al., 1984). The foregoing variable pattern of frequency change that may be seen in scalp-recorded seizures contrasts to the tendency toward a smooth progressive slowing of seizure discharge frequency when recorded with implanted electrodes.

A possible explanation for the first two differences, which was advanced by Gloor (1975), is as follows. Seizure discharges tend to have a faster frequency when recorded early after onset and near the site of origin, whereas they tend to be slower in frequency when recorded later during the metamorphosis of the seizure discharge and further from the site of origin. Scalp-recorded locations are often some distance from the primary generator, and therefore, before detection by scalp electrodes, the seizure discharge may have slowed considerably during its spread in time and space from a distant origin (Geiger and Harner, 1978; Blume et al., 1984).

It is more difficult to explain the third area of difference between scalp-recorded and implanted-electrode-recorded seizures. That is the more unpredictable direction of frequency change during the earlier metamorphic phases of a scalp-recorded seizure versus the progressive slowing of most seizure discharges recorded with implanted electrodes. One possible explanation for a frequency increase during the earlier phases of some scalp-recorded seizures was advanced by Blume (1984), who suggested scalp-recorded frequency increases might reflect a distant area's tendency to generate a new and faster discharge in response to an earlier lower frequency input from the primary ictal source.

Postictal changes commonly follow focal metamorphic seizures, being seen in approximately 70% of patients in two separate studies (Kaibara and Blume, 1988; Walczak et al., 1992). The variety of postictal changes includes: attenuation of normal background, focal delta activity (Klass, 1975; Kaibara and Blume, 1988; Walczak et al., 1992), and activation of focal spikes (Gotman and Marciani, 1985; Kaibara and Blume, 1988). Postictal changes are a good lateralizing sign but not as useful as the rhythmic seizure discharge itself (Walczak et al., 1992).

EXTRATEMPORAL COMPLEX PARTIAL SEIZURES

Except for their spatial distribution, the scalp-recorded metamorphic patterns of extratemporal seizures is similar to that in temporal seizures. There are, however, a few notable differences.

The initial scalp-detected phase of an extratemporal seizure is more likely to be in the beta frequency range than is the case for temporal seizures. This
may be related to the fact that scalp electrodes are located nearer to the foci in the lateral extratemporal cortex than they are to the foci in the medial temporal structures. Based on the previously reviewed explanation by Gloor (1975), one would expect that the extratemporal foci nearer the scalp electrodes would be detected earlier when the discharge was still at a fast frequency and low amplitude (Fig. 4).

Another important difference when comparing extratemporal frontal to temporal complex partial seizures is that it may be more difficult to detect a scalp-recorded discharge with the frontal than it is with the temporal seizures (Williamson et al., 1985; Quesney, 1987; Wallczak et al., 1992). Part of this difficulty likely lies in a common clinical difference between frontal and temporal automatisms. Frontal automatisms have shorter durations (less than 30 s) and agitated tempo episodes with little or no aura or postictal state. By contrast, temporal automatisms are more commonly longer (more than 30 s), slower tempo episodes with more frequent aura and a postictal state. The brief frontal seizures are more likely to generate only the low-voltage fast discharge phase of a metamorphic seizure that is easily obscured by the excessive muscle activity associated with its agitated behavioral automatism. Further, because of its short or absent clinical postictal state, frontal automatisms are less frequently followed by a postictal EEG change than are temporal automatisms.

Not only is it more difficult to detect a scalp discharge in a frontal than a temporal seizure, accurate lateralization of the focus (as judged by postoperative freedom from seizures) is less often achieved in frontal than it is in temporal seizures. However, a scalp seizure discharge will usually accurately lateralize the seizure focus if it is consistently lateralized throughout two or more ictal phases into a postictal state (Wallczak et al., 1992).

REFERENCES


