**Ictal and interictal**

**Surface of EEG patterns in epilepsy**

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**ABSTRACT**

Extracranial electroencephalogram (EEG) is an important neurodiagnostic test in the diagnosis and evaluation of epileptic disorders. Interictal extracranial EEG patterns are categorized into non specific patterns such as distorted normal EEG patterns or abnormal slow activity which indicate neurophysiological disturbance or cortical dysfunction related to seizures, epileptic lesions or antiepileptic drugs. Non specific EEG patterns are focal or generalized. Specific interictal EEG patterns are patterns of interictal epileptic discharges (IEDs) and include spikes, sharp waves or spike slow wave complexes. Interictal epileptic discharges are focal or generalized. Detection of IEDs on extracranial EEG depends on the seizure type, epileptic syndrome, location of the epileptic focus in partial epilepsies, age of seizure onset and methodology of recordings. Ictal EEG patterns provide valuable clues for diagnosis of epileptic and non-epileptic episodes, classification of epileptic syndromes and localization of epileptic foci in intractable partial epilepsies for epilepsy surgery. This syllabus provides an introduction to common interictal and ictal patterns in extracranial EEG and discusses limitations of extracranial EEG recordings.

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Extracranial EEG recording of seizures is performed for specific clinical indications. It is utilized to differentiate epileptic from non-epileptic episodes, to study the specific patterns of epileptic seizures, or as part of a comprehensive pre-surgical evaluation of medically intractable epilepsies for epilepsy surgery. Issues other than diagnostic specifications of seizure type might be addressed by extracranial EEG recording such as clues to potentially important alternative mechanisms of ictal generation, propagation and termination. Extracranial EEG recordings are subject to technical limitations.

**Limitations of extracranial EEG recordings.**

Extracranial EEG recordings are fundamentally limited. Surface recordings detect only a portion of the underlying brain electrical activity which can be delineated by intracranial techniques with greater resolution. Several factors contribute to this limitation. As the amplitude of any recorded electrical signal is inversely proportional to the square of the distance from the signal origin to the recording electrode, this explains the low resolution of the extracranial EEG signals. Another factor which affects the detection of surface EEG signals is the degree of synchrony at the cortical level. Experimental studies have shown that a minimum of 6 cm² of cortical surface must be at least partially involved with a synchronous discharge before detection of the electrical signal extracranially. In addition, the impedance properties of the intervening layers of brain parenchyma, cerebrospinal fluid, meninges, skull and scalp interferes partially with the conduction of electrical signals. An additional factor of significance is the geometric orientation of the recording electrode to the dipole generator of the electrical signal as a relatively small change in the electrode position may result in marked reduction of amplitude of recorded electrical.

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signal if the change in the electrode position alters the subtended solid angle. Despite these limitations of the extracranial EEG recording it remains an excellent overview of regional and global electrical activity.\textsuperscript{1,2}

**Interictal EEG patterns in epilepsy.** The interictal EEG patterns in epilepsy can be categorized into non-specific non-epileptiform patterns which are not by themselves an indication of increased epileptiform potential, and specific epileptiform patterns which carry diagnostic value.\textsuperscript{1,2}

**I. Non epileptiform patterns.** Distorted normal patterns such as distortion of the alpha frequency or amplitude reduced beta activity or reduced vertex sharp waves and sleep spindles at the side of the epileptogenic lesion. Abnormal patterns such as generalized or regional slow activity indicate the presence of neurophysiological disturbance related to the epileptogenic lesions, epileptic seizures or antiepileptic drugs.\textsuperscript{1,2}

**II. Epileptiform discharges.** The main types of epileptiform discharges are spikes and sharp waves occurring as either singles potentials or followed by a slow wave namely, spike wave complex. Spikes are predominantly negative sharp transients with duration of 20-70 milliseconds. Sharp waves are also sharp transients but of a broader duration of 70-200 milliseconds. These abnormalities should have a physiologic potential field and involve more than one electrode to exclude artifacts. Spike wave complexes may come isolated or in runs. The percentage of patients with epilepsy who have epileptiform discharges in the initial EEG vary from 30-50%. This percentage increases with subsequent EEGs to 80-90%. The frequency of spiking is not a predictor of the seizure activity and is not influenced by antiepileptic drug levels. However certain antiepileptic drugs such as barbiturates, valproate and benzodiazepines may decrease epileptiform discharges.\textsuperscript{2} The recording of interictal epileptiform activity depends on the seizure type, localization of the epileptogenic zone, recording methodology and age at seizure onset. Some EEG sharp phenomena such as small sharp spikes, 14 and 6 positive spike bursts, 6 Hz spike and wave, wicket rhythm, psychomotor variant pattern, rhythmic temporal activity of drowsiness are not associated with increased epileptogenic potential.\textsuperscript{1,2}

**A. Focal or regional epileptiform discharges.** These include focal spikes, sharp waves, spike wave complexes and periodic lateralized epileptiform discharges (PLEDS). The focal epileptiform discharges are not only diagnostic of partial epilepsy but correlate with epileptogenesis and seizure origin.\textsuperscript{1,2}

**Interictal EEG patterns in temporal lobe epilepsies.** Temporal intermittent rhythmic delta activity (TIRDA) correlates strongly with the diagnosis of temporal lobe epilepsy. It appears more with mesial temporal lobe epilepsy in 80-90% of patients and ipsilateral to the hippocampal atrophy on the magnetic resonance image of the brain. Intercitial discharges (IEDs) are seen in 95-98% of temporal lobe epilepsy patients. Temporal IEDs are commonly seen together with TIRDA in patients with temporal lobe epilepsy. Their frequency is more in medically refractory patients with history of febrile convulsions and hippocampal sclerosis HS. With HS the IEDs are usually ipsilateral to the epileptic focus and usually restricted to the anterior temporal electrodes F7, F8 and sphenoidal electrodes (Figure 1). Bilateral independent temporal slowing, spikes or sharp waves occur in 14-42% of patients, and reflect bilateral disease. In strictly unilateral benign temporal tumors, bilateral IEDs are seen in 22-34% of patients. Most studies comparing neocortical temporal lobe epilepsy to mesial temporal lobe epilepsy found no differences with respect to spike frequency, unilateral or bilateral IEDs, non sphenoidal spikes or focal slowing.\textsuperscript{1,5}

**Interictal EEG patterns in extratemporal epilepsies.** Although extracranial EEG may not determine with precision localization of neocortical epileptogenic foci, it does contribute to the diagnosis of neocortical epilepsy. In frontal lobe epilepsy lateralized but not localized IEDs are seen in 59% of patients. Localized IEDs are seen in only 9% of patients. Generalized interictal discharges with secondary bilateral synchrony (Figure 2) can be seen with frontal lobe epilepsy. Supraorbital surface electrodes may increase the sensitivity of extracranial EEG recordings in frontal lobe epilepsy. Occipital IEDs are less common than frontal or temporal IEDs. Occipital spikes occur more in children and indicate epileptogenesis in 40-50% of patients. Occipital spikes also occur with congenital blindness without epilepsy. Occipital IEDs may be unilateral or bilateral. In addition to lesional occipital lobe epilepsy occipital IEDs are seen in idiopathic partial epilepsy the benign partial epilepsy with occipital paroxysms (Figure 3). In perirolandic epilepsies IEDs are less common than temporal IEDs. The interpretation of IEDs in perirolandic epilepsy may be difficult as many normal sharp EEG patterns are seen in the central region such as Mu rhythm and the vertex sharp waves during sleep. Central spikes are associated with epilepsy in 40-60% of patients. In benign partial epilepsy with centrotemporal spikes the interictal EEG is characterized by unilateral or bilateral high voltage diphasic spike followed by slow wave with duration of 200-300 milliseconds at central and midtemporal regions, with a surrounding region of positivity suggesting a tangential dipole source (Figure 4).\textsuperscript{1,2,6,7}

**B. Generalized epileptiform discharges.** Burst suppression patterns (Figure 5). This EEG pattern is seen with early epileptic encephalopathies such as the myoclonic encephalopathy and early infantile epileptic encephalopathy of Ohtahara.\textsuperscript{2}

**Hypsarrhythmia (Figure 6).** This EEG pattern is the most common interictal EEG pattern with infantile spasms. It appears in 40-70% of cases. The tonic spasms are accompanied by a sudden electrodecremental response with low voltage high frequency waves superimposed.\textsuperscript{2} (see below in ictal patterns)
Extracranial EEG patterns in epilepsy ... Khan

Figure 1 - Interictal epileptic discharges in mesial temporal seizures with phase reversal at left sphenoidal regions SP1.

Figure 2 - Interictal epileptic discharges with secondary bilateral synchrony in mesial frontal seizures. Note the focality at F4 (arrow).

Figure 3 - Interictal epileptic discharges in benign partial epilepsy with occipital paroxysms. Note the independent high amplitude interictal epileptic discharges in both occipital regions.

Figure 4 - Left midtemporal and central interictal epileptic discharges of benign epilepsy with centrotemporal discharges. Note the positivity at midtemporal.

Figure 5 - Burst suppression pattern characteristic of early infantile encephalopathies. Note the prolonged periods of generalized background flattening. (arrows).

Figure 6 - Hypsarrhythmia. Note the high amplitude disorganized EEG background with multiple independent bilateral interictal epileptic discharges (arrows).

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Figure 7 - Generalized slow spike wave discharges at 1.5-2 Hz. Note the gradual end (arrows) and the appearance of focal discharges (arrowhead).

Figure 8 - 3Hz generalized spike wave discharges. Note the abrupt onset and the abrupt end and the lack of post ictal slowing (arrows).

Figure 9 - Generalized fast polyspike wave discharges. Note occasional focality (arrows).

Figure 10 - Ictal pattern in left mesial temporal seizure. Note the initial generalized background attenuation (arrow) followed by the left temporal rhythmic theta of 5-7 Hz (arrowhead).

Figure 11 - Non lateralized ictal EEG onset in lesional perirolandic epilepsy (arrow).

Figure 12 - Ictal onset in lesional occipital lobe epilepsy. Note the right occipital regionalized rhythmic theta activity (arrow).
Generalized slow spike wave discharges (Figure 7). The frequency of these discharges is below 2.5 Hz. Hyperventilation has little effect on these discharges and photic stimulation has none. Sleep increases their abundance and the EEG background is usually slow. The incidence of these discharges is maximum in children between one and 5 years. The discharges are not necessary time locked with seizures. The most common seizure type accompanied with this pattern are atypical absence seizures. Atonic, myoclonic and tonic clonic seizures are also seen. These generalized slow spike wave discharges occur very often in Lennox Gastaut syndrome a generalized symptomatic or cryptogenic epileptic syndrome in children above the age of 2 years with mental retardation and multiple seizures types.\(^1,2,8\)

Generalized 3 Hz spike wave discharges (Figure 8). This generalized interictal pattern is characteristic of typical absence seizures. The 3Hz spike wave discharges are regular synchronous and timed locked with clinical absence seizures therefore the numbers of the discharges correlate with the number of absence seizures and EEG may be used to assess the effectiveness of therapy. The EEG background is usually normal and occasional focality may occur. Hyperventilation is a well known activator of the generalized 3 Hz spike wave discharges. Photic stimulation may elicit the 3 Hz spike wave pattern in 10\% of patients with epilepsy especially if the patient has additional seizure types to the absence such as generalized tonic clonic seizures or myoclonic seizures. Eye closure during photic stimulation may bring out the generalized spike wave discharges. During sleep the generalized 3 Hz spike wave discharges may be less regular with polyspikes and fragmentation. Classical epileptic syndromes with 3 Hz spike wave discharges include childhood absence epilepsy, myoclonic absence epilepsy and absence epilepsy with eyelid myoclonia.\(^1,2,8\)

Generalized fast polyspike wave discharges (Figure 9). As the name implies, the generalized discharges are of a faster frequency than the 3 Hz generalized spike wave discharges. They occur at 4-6 Hz and are composed of short generalized bursts of polyspikes wave discharges usually time locked with clinical myoclonus if the patient has myoclonic seizures. Photoconvulsive response occurs in 30-40\% of patients with this EEG pattern and a minority will have polyspikes wave discharges upon eye closure. The EEG background is usually normal. Some focality in the EEG may be seen. This EEG pattern occurs classically with juvenile myoclonic epilepsy and primary generalized epilepsy with generalized tonic clonic seizures upon awakening.\(^1,2\)

A specific generalized pattern of continuous spike wave discharges during non REM sleep is seen with Landau-Kleffner syndrome.\(^2\) It is of importance to mention in the differential diagnosis of generalized fast polyspike discharges the pattern of secondary bilateral synchrony which occurs with mid line cerebral lesions or in frontal lobe epilepsy. The EEG burst is often very irregular and may be preceded by a focal onset (Figure 2).\(^6\)

Generalized spike wave discharges with deterioration of the EEG background. Generalized spike wave discharges accompanied with progressive deterioration of the EEG background is a classical interictal EEG pattern of progressive myoclonic epilepsies which are characterized by progressive neurological and cognitive deterioration, ataxia and multiple generalized and partial seizures. Examples include mitochondrial encephalopathies such as mitochondrial encephalopathy with red ragged fibers MERRF, Lafora body disease and Unverricht-Lundborg disease. A variable degree of focality and photosensitivity is seen with this EEG pattern depending on the underlying disease.\(^2\)

Ictal EEG patterns in epilepsy. The ictal EEG onset of a seizure is characterized by a sudden alteration of the EEG background, appearance and evolution of a new rhythm. The ictal EEG patterns can be categorized into patterns of partial seizures, namely, seizures characterized by clinical and EEG evidence of seizure origin from a limited region in one cerebral hemisphere, and patterns of generalized seizures namely, seizures characterized by initial clinical and EEG changes indicating widespread and synchronous involvement of both cerebral hemispheres.\(^1,2\)

A. Ictal EEG patterns in partial seizures. Partial seizures are classified as simple partial seizures during which no alteration of consciousness occur, complex partial seizures during which consciousness may be altered and partial with secondary generalized tonic clonic seizures. Auras are considered as simple partial seizures. During a simple partial seizure, no discernible extracranial EEG changes occur in standard EEG monitoring. A small series of patients studied with expanded arrays of surface electrodes indicated that 35\% of isolated simple partial seizures may be accompanied by surface EEG changes. Extracranial EEG recordings of complex partial seizures and partial with secondary generalized seizures nearly always show discernible changes. The recorded ictal EEG patterns differ according to the localization of the epileptic focus.\(^1,2\)

Temporal lobe seizures (Figure 10). Temporal lobe seizures arise either from the hippocampus and other medial temporal structures (mesial temporal seizures) or from the lateral neocortical temporal structures (neocortical temporal seizures). Extracranial EEG ictal onset of mesial temporal lobe seizures is characterized by diffuse attenuation of the background and cessation of interictal spiking. Occasional lateralization or localization of the attenuation may occur. This is followed by rhythmical discharges of 5 Hz or faster with maximal amplitude at one temporal region. This temporal rhythm appears after the initial attenuation or after a phase of lateralized or bilateral rhythmical changes. The lateralized temporal rhythm occurs in 50-90\% of mesial temporal seizures and provides strong evidence of ictal origin in the same temporal region.
Evolution of the ictal rhythm into faster rhythm followed by slower waves until there is ictal termination. Propagation of ictal discharges into contralateral temporal regions is often delayed. Lateralized post ictal slowing ipsilateral to the temporal focus occurs in 67-70% of patients. Ictal onset of neocortical temporal seizures is characterized by lateralized temporal rhythmic theta activity usually faster than 6.5Hz. This temporal rhythm is often preceded by lateralized or bilateral pleomorphic delta activity. Bilateral onset occurs in 20% of neocortical temporal seizures. Contralateral ictal onset occurs in 3% of neocortical temporal seizures. The bitemporal spread of ictal discharges occurs more often and more rapid in neocortical temporal lobe seizures in comparison to mesial temporal seizures.1,5

Extratemporal lobe seizures. The localizing value of extracranial ictal EEG patterns in extratemporal epilepsies is inferior to temporal lobe epilepsies, 47-65% of extratemporal seizures are correctly lateralized as compared to 76-83% of temporal lobe seizures. With frontal lobe seizures variable ictal patterns are described depending on the location of the epileptic focus in the frontal lobe. Parietal lobe and periorbital seizures (Figure 11) are often non localized and only 10% of seizures are accompanied with focal ictal onset especially if expanded arrays of electrodes are used. Ictal onset of occipital seizures is regionalized to posterior regions of ipsilateral cerebral hemisphere in 50% of patients (Figure 12). In less than 20% of cases, focal ictal onset at ipsilateral occipital lobe is seen. The most common ictal propagation pattern is to the ipsilateral or bilateral mesial temporal regions. Alternative ictal propagation pattern is to the parietal or frontal lobes.1,2,6,7

B. Ictal EEG patterns in generalized seizures. Typical absence seizures. These seizures are time locked with the generalized regular 3 Hz spike wave discharges described above. The ictal onset may start with discharge frequency faster than 3 Hz and end with a discharge frequency slower than 3 Hz. The onset and the end are usually abrupt. No post ictal slowing follows (Figure 8).1,2,8

Atypical absence seizures. These seizures are so called because they are often accompanied clinically by alteration of the tone. The extracranial ictal EEG starts with nonsynchronous bilateral slow spike wave discharges with a gradual onset and end, marked irregularity and fragmentations (Figure 7).1,2,8

Myoclonic seizures. The brief sudden irregular contractions of many muscles in myoclonic seizures are accompanied with time locked fast polyspike waves discharges (Figure 9).1,2

Tonic clonic seizures. These seizures often start clinically with a loud cry followed by the tonic phase which lasts up to 30 seconds then the clonic phase which is usually less than 2 minutes. The tonic phase is accompanied by an initial diffuse voltage attenuation superimposed with very fast low amplitude waves of 20-40 Hz and muscle artifacts. The clonic phase is accompanied by multiple spike clusters followed by slow waves. The frequency and duration of the multiple spike clusters reduce as the clonic phase is approaching the end. This is followed by diffuse post ictal slowing. The secondary generalized seizures follow the same ictal EEG patterns but may start with a lateralized or localized onset.1,2

Tonic seizures. Such as the bilateral brief tonic spasms in West syndrome. These are accompanied by generalized paroxysmal fast activity which may show a gradual increase in amplitude with decreasing frequency or an initial paroxysmal high amplitude slow or sharp wave followed by a brief period of generalized attenuation of the background time locked with tonic seizures.1,2

Atomic seizures. These seizures are characterized clinically by brief episodes of generalized loss of tone. Variable ictal EEG patterns are described with atomic seizures such as bilateral spike wave discharges, diffuse voltage attenuation or generalized fast activity.1,2

Clonic seizures. Isolated clonic seizures are rare and the ictal EEG pattern is similar to that of the clonic phase of generalized tonic clonic seizures.1,2

In conclusion, the extracranial interictal and ictal EEG patterns show considerable variability between different seizure types. With partial seizures, detection and localization of IEDs and ictal EEG onset depends on the localization and the nature of the epileptic focus. Yet extracranial EEG remains a powerful neurodiagnostic study that provides clues for diagnosis of epileptic disorders, classification of seizure types, monitoring response to therapy and presurgical evaluation of epilepsy surgery.

References