There is now considerable evidence from studies in experimental animals to suggest that the rhythmic activity normally recorded from the scalp has a cortical origin, being derived from the postsynaptic potentials of cortical neurons. In particular, it is the pyramidal neurons—cells that are vertically oriented with regard to the cortex and have a large apical dendrite extending toward the surface—that are important in this respect, while potentials arising from neuronal activity in subcortical structures or from horizontally oriented conical cells contribute little, if anything, to the normal, scalp-recorded EEG.

The cortical activity has a regular rhythmicity which seems to depend on the functional integrity of subcortical mechanisms. In the cat, for example, rhythmic cortical activity persists after the brainstem has been sectioned between, or just above, the colliculi, but is much reduced when the cortex is isolated by cutting its connections to other parts of the brain. The results of other lesion experiments suggest that it is the thalamus which serves as pacemaker of certain cortical rhythms that are recorded at electroencephalography. The midline nuclei of the thalamus were important in this respect, and this concept was subsequently modified and the activity from these nuclei relayed in various other intrathalamic nuclei before being projected to the cortex (Fig. 1).

This has led to the so-called facultative pacemaker theory in which thalamic rhythmicity is related to a recurrent inhibitory process, as shown in Fig. 2. Postsynaptic inhibitory potentials have a synchronizing effect on the activity of thalamic cells, thereby leading to the generation of a series of excitatory waves and governing the interval between successive waves. Rhythmic activity can arise in any or all of the thalamic nuclei, can spread from one nucleus to another, and is imposed on the cortex via the thalamocortical projections (Fig. 3.).

Figure 1. The midline pacemaker theory. Rhythmic activity is imposed upon widespread cortical areas via a multineuronal system, including the intralaminar nuclei, the anterior thalamic nucleus (VA), and the thalamic reticular nucleus (Ret). (A) Association, (M) medial thalamic nuclei. The cortical projection from the relay nuclei (R) is separate from the rhythm-inducing system.

Figure 2. Schematic representation of the proposed inherent mechanism giving rhythmic discharges of thalamic neurons. (A) a discharge of the cell (hatched) causes recurrent inhibition via an interneuron (black) that hyperpolarizes many neighboring projection cells. During the postinhibitory rebound, many of these cells discharge action potentials and an increasing number of cells participate during the successive cycles (A, lower part). Alternatively, intrathalamic connections via distributor neurons (B) spread the rhythmic activity from one group to other parts of the thalamus (from-left-to-right group.)
Alpha Rhythm

Alpha rhythm has a frequency of between 8 and 13 Hz, is found posterior portions of the head during wakefulness, and is best seen when the patient is resting with eyes closed. It is attenuated or abolished by visual attention, and transiently by other sensory stimuli. Alpha activity is well-formed and prominent in some normal subjects, while in others it is relatively inconspicuous. Its precise frequency is usually of little diagnostic significance, unless information is available about its frequency on earlier occasions.

Slowing occurs with advancing age, as a consequence of certain medication such as anticonvulsant drugs, and in patients with clouding of consciousness, metabolic disorders, or virtually any type of cerebral pathology. The alpha activity may increase in frequency in children as they mature, and in older subjects who are thyrotoxic. A slight asymmetry is often present between the two hemispheres with regard to the amplitude of alpha activity and the degree to which it extends anteriorly. In particular, alpha rhythm may normally be up to 50 percent greater in amplitude over the non-dominant hemisphere. A more marked asymmetry of its amplitude may have lateralizing significance but is difficult to interpret unless other EEG abnormalities are present, because either depression or enhancement may occur on the side of a hemisphere lesion. Similarly, a persistent difference in alpha frequency of more than 1 Hz between the two hemispheres is generally regarded as abnormal, but it is usually difficult to be certain which is the abnormal side unless other abnormalities are also found.

Beta Activity

EEG CHANGES DUE TO A PURELY CORTICAL LESION NOT INVOLVING SUBCORTICAL WHITE MATTER

A purely cortical lesion can be due to extraaxial tumors like meningiomas, cortical atrophy and others. In this situation cortical neurons are unhealthy, diseased (by edema, compression of ischemia...etc.) yet not deafferentated from the subcortical pace-maker.

EEG activity recorded from diseased, well afferentated cortical neurons (that are not cut from the pace-maker) are not as chaotic and as slow as EEG activity recorded from deafferentated healthy neurons. If the later is called polymorphic delta activity, the former is better called polymorphic theta activity.

Polymorphic theta activity is generated from neurons that are still paced by the subcortical pace making neurons, these cortical neurons will fire at a faster rate (theta range) compared with completely deafferentated neurons and because they are still driven by the subcortical pace maker, their activity is faster, more regular and more synchronous (compared with deafferentated neurons) with less variability in shape, duration and amplitude of recorded EEG waves. While neurons that are completely deafferentated and cut from the deep
subcortical pace-making neurons will fire at their own slow rhythm (delta range) and because they are no longer driven by the subcortical pace
maker, their activities is more chaotic, irregular and less synchronous with much more variability in shape, duration and amplitude of recorded
EEG waves. (Polymorphic delta activity).

Unhealthy, diseased cortical neurons, that are uncut from the incoming arousal stimuli but still viable, will not respond to the incoming arousal
stimuli by degenerating alpha spindles (which is the normal situation), but rather their response will be down-shifted to the theta range
(Polymorphic theta activity). The generated theta waves will not be as organized as the alpha spindles but, at the same time, will not be a chaotic, irregular and variable as the polymorphic delta activity that are generated by deafferentated neurons.

Polymorphic theta activity maps exactly the diseased neurons and points to the anatomical site of the lesion (picked up from electrodes
that overly the lesion), this is in contrast to polymorphic delta activity which is projected to a much wider cortical area and has no localizing
significance in so far as the anatomical site of the lesion is concerned. However it should be mentioned that the theta focus is totally non-specific and tells us about the nature of the cortical pathology.

In general a purely cortical destructive lesion of any etiology produces focal increase of percentage theta activity (that is lateralised to the anatomical site of the destructive lesion and exactly maps it). The theta focus is not accompanied with any increase in the percentage delta activity. Alpha maps might be normal or might show occipital reduction of the percentage Alpha activity ipsilateral to the cortical destructive lesion. Beta percentage activity maps might show a focal increase (that is lateralised to the anatomical site of the cortical lesion and might be present in the same electrodes that show the theta focus). The beta focus (when present) probably indicates the existence of cortical irritability.

**A SUBCORTICAL WHITE MATTER DESTRUCTIVE LESION**

Polymorphic delta activity (PDA) consists of arrhythmic slow waves that vary in frequency, amplitude, and morphology. PDA can occur in either a focal or generalized distribution. Continuous PDA is indicative of abnormalities involving subcortical white matter. One of the shortcomings of standard scalp EEG recordings is their limited spatial resolution. This holds true for the relationship of PDA to an underlying structural abnormality. Not only is the inherent localizing ability of the scalp EEG limited, but also the PDA of a structural lesion is referable not to the lesion itself but to the surrounding brain tissue. Because of this limitation, the area of a lesion is indicated not by the maximal amplitude of PDA but rather by a region of relatively low-amplitude slowing. Continuous, rather than intermittent, PDA is associated with large lesions, mass effect, and impairment of consciousness.

Persistent polymorphic delta activity may not precisely match the true location of the lesion, particularly since it presumably arises from physiological deranged neurons often lying on the margin of the destructive lesion. Persistent polymorphic delta activity is aetiologically nonspecific and is seen in a variety of subcortical (white matter) destructive lesions including neoplasms, infarctions, abscesses, trauma, and haemorrhage. It can also be seen in reversible processes such as focal ischemia in transient ischemic attacks or focal depression from a recent seizure.

**Pathophysiology and clinical significance of polymorphic delta activity**

The diencephalon, as the pacemaker of EEG activity, sends arousal stimuli (through the thalamocortical pathways) to the cortical neurons which respond by generating the EEG waves. There are always a good degree of coherence and bilateral symmetry of the generated EEG waves because cortically neurons are paced by the subcortical pacemaker). Any subcortical destructive focal lesion (like infarction, abscess, tumors...etc.) interrupting the thalamocortical pathway will deprive the cortical neurons, in a particular cortical area, from the arousal stimuli resulting in cortical neuronal physiological dysfunctions. The neurons in that area, being deafferentated and deprived form the thalamocortical
arousal stimuli, will fall out of synchrony and coherence and will start to generate waves in a chaotic pattern and at a much slower rate than normal, these waves are irregular in shape, amplitude and duration, and shows little variation with change in the physiological state of the patient. Cortical neurons, in the deafferentated cortical strip, are no longer paced (being cut from the pace maker by the subcortical destructive focal lesion) and each neuron will fire at its own rhythm resulting in polymorphic delta activity. Polymorphic delta activity is due to deafferentation of physically normal cortical neurons by a subcortical destructive white matter focal lesion. Only subcortical white matter focal lesions can produce Polymorphic delta activity (PDA) and purely cortical lesions do not produce PDA.

**Please note**

1- Cortical neurons that generate PDA are physically normal, however they are simply deafferentated, physiologically deranged and deprived from arousal stimuli.

2- PDA poorly localizes the destructive subcortical area and is generated from a much wider cortical area overlying the subcortical destructive focal lesion which is spatially much smaller than the affected cortical area that generates the PDA. The subcortical destructive focal lesions simply act by deafferentation of the cortical strip which contains the physiological deranged neurons that generate the PDA.

3- A cortical lesion that organically and physically affects cortical neurons (either a primary cortical lesion, a subcortical focal lesion extending to the cortical neurons or an extra-axial focal lesion compression or extending to the cortical neurons) does not produce PDA. Only normal, physiological deafferentated, cortical neurons are capable of producing PDA.

**Brainmapping Correlates of PDA**

1. Theta percentage activity is focally increased, the theta focus exactly maps and matches the anatomical site of the lesion.

2. Delta percentage activity is diffusely increased and is projected to the cortical area dysfunctioned by the subcortical destructive lesion. The delta percentage activity is seen surrounding the theta focus and mapping the deafferentated cortical electrodes areas that showed PDA in conventional EEG. The delta wave projection, spatial extension, distribution, and percentage activity correlates nicely with the clinical picture and the degree of clinical disability.

3. The alpha and beta percentage activity are reduced in the affected hemisphere. Alpha is maximally reduced in the delta area while the beta percentage activity is maximally reduced in the theta focus area.

The pattern described above is aetiologically non-specific and occurs due to any destructive subcortical lesion of any aetiology.

The percentage delta activity maps the dysfunctioned cortical zone and exactly correlates with the clinical picture. The patient in figure 8 map presented clinically with left sided weakness and expressive aphasia due to a subcortical lacunar infarction. The delta activity is lateralized to the left frontal region in electrodes FP1, F7. The same electrodes area showed polymorphic delta activity on conventional EEG. That is to say delta activity, in this patient, is projected to the dysfunctioned cortical area and exactly correlates with the clinical picture. As is the case with polymorphic delta activity, delta activity was generated by deafferentated, physically normal cortical neurons.

In this patient theta maps showed focal increase in the percentage activity that was recorded from the cortical area that exactly overlies the deep destructive lesion. The theta focus, in this patient, showed a fairly good anatomical localization of the subcortical destructive lesion that exactly correlated with MRI study (theta band points to the site of the lesion). Probably this focal theta activity was generated by neurons in the cortical
strip that directly overlies the deep lesion, these neurons are probably physically abnormal and is directly involved by the pathological process through the effect of edema or ischemia. These neurons are not deafferentated by the subcortical destructive lesions but rather they are directly affected by the pathological process. Because of their close proximity to the lesion, these neurons are probably directly implicated by the subcortical lesion by edema or ischemia.

Careful inspection of the conventional EEG data recorded at the same time from the electrodes that generated the focal theta activity by brainmapping showed polymorphic theta activity, however this theta activity was not as disorganized as the polymorphic delta activity, although it showed variability in wave morphology, amplitude and duration. EEG wave recording from healthy, yet deafferentated cortical neurons is more likely to produce EEG activity that is much slower and more disorganized than EEG recording from diseased, yet pacemaker connected neurons.

Percentage alpha activity is almost invariably reduced in the affected hemisphere. The alpha activity is particularly markedly reduced at electrodes which show maximum delta activity. Alpha visual reactivity is impaired (diminished or reversed). Alpha percentage activity correlates inversely with the degree of clinical disability (The less alpha, the more of the clinical disability). Alpha percentage activity is an indicator of a more global hemispherical impairment than delta or theta activities which probably indicate a more focal or regional impairment restricted to regions of maximum theta or delta activity. Beta percentage activity is commonly focally reduced at the electrodes which show focal theta activity. Beta activity might be increased in some patients, a pattern which probably indicates the existence of cortical irritability.

Subcortical diencephalic lesion

Subcortical gray matter lesions: Intermittent rhythmic slow wave activity

Subcortical gray matter lesion involving the EEG pace-maker generates intermittent delta activity which has the following characteristic

- Consists of sinusoidal waveforms of approximately 2.5 Hz that occur intermittently in the EEG recording. It is most often symmetric but can be lateralized.

- In adults, the delta activity has a frontal predominance (frontal intermittent rhythmic delta activity [FIRDA]). In children, it is maximal posteriorly (occipital intermittent rhythmic delta activity [OIRDA])

- The intermittent rhythmic delta activity shows visual reactivity and is commonly suppressed in the eye open state unless the patient is comatose.

- Intermittent rhythmic delta activity is associated with structural lesions, most commonly diencephalic, infratentorial or intraventricular tumors, or with diffuse encephalopathies.

- FIRDA occurring in patients with a normal EEG background suggests that the pattern is due to a structural lesion; when associated with EEG background abnormalities, it is likely to be due to encephalopathy.

- OIRDA is associated with absence epilepsy in children aged 6-10 years.
1-Intermittent rhythmic slow wave activity is seen in diffuse encephalopathic process (except hepatic encephalopathy which has a different brainmap spectral profile as will be explained in a different issue) and in middle line thalamic, or huge parasellar or infratentorial tumors. It was also seen by the author in vertebro-basilar insufficiency and migraine.

2-There is reduction of alpha percentage activity, and reduced or reversed alpha visual reactivity. The degree of reduction of alpha percentage activity correlates with prognosis. The alpha topography is normal and retains its middle line topography with posterior maximum and is more reduced anteriorly than posteriorly. There is a fairly good degree of symmetry, synchrony and coherence in alpha percentage activity maps. however it is not very infrequent to see some degree of asymmetry with more alpha percentage activity seen on one side than the other.

3- The alpha land (the middle line electrodes) is now occupied by theta and delta percentage activity, which is now maximum in the middle line electrodes at F3,F4,O2,O1. The maximum middle line percentage activity is now shifted down to the theta rage in most patients and occasionally to the delta rage depending on the severity of the encephalopathic process and the state of the patient. Combined theta and delta percentage activity maps clearly demonstrates the midline maximum. The topography of theta percentage activity is identical to that of normal alpha percentage activity maps in the eye closed state. Slow wave activity commonly show visual reactivity exactly as alpha percentage activity behaves under normal physiological conditions.

4- There is a fairly good degree of symmetry, synchrony and coherence in theta percentage activity. However it is not very infrequent to see some degree of asymmetry with more theta percentage activity seen on one side than the other.

5- Beta percentage activity is reduced in the midline frontal, central/parietal and occipital electrodes.

Because the intermittent rhythmic slow wave activity occupies the same electrode regions that are normally occupied by the alpha activity, so it looks like that both (the intermittent rhythmic slow wave activity and alpha spindles) share a common generator. Similarities between both activities are:

1. **Both are sinusoidal activity that waxes and wanes (intermittent)**

2. **Both show visual reactivity**

4. **Both are maximum in the middle line electrodes**

So it looks like that the generator that is responsible for the generation of the intermittent rhythmic slow wave activity is the same generator that is responsible for the generation of alpha spindles under normal conditions, however in the former condition the generator (the pace-maker) is diseased and firing at a lower rate.

A dysfunctioned pacemaker (subcortical gray matter, diencephalon) is probably necessary for the intermittent slow wave activity to be seen on EEG.

Arousal stimuli in the thalamo-cortical circuitry are responsible for the production of alpha spindles under normal physiological conditions. However when a diffuse encephalopathic process involves the diencephalic neurons bilaterally, the dysfunctioned diencephalic neurons fire at a slower rate and instead of producing alpha spindles they produce theta or delta spindles that retain the same characteristics of alpha spindles in spatial topography and visual reactivity.
In intermittent rhythmic slow wave activity cortical gray matter is not necessarily abnormal as this phenomenon is also observed in middle line tumors (thalamic) and some extra-axial tumors in the parasellar and infratentorial regions. A dysfunctioned subcortical gray matter affecting the diencephalic pace-making neurons is necessary for the generation of intermittent rhythmic slow wave activity. The diencephalic pace-making neurons are necessary for the genesis of alpha spindles under normal physiological conditions.

In intermittent rhythmic slow wave activity there is a down-shift of the predominant middle line activity (the alpha land) from the alpha range to lower frequencies in the theta and delta ranges. In the author experience the predominant middle line activity is down-shifted to the theta range more often than the delta range. The condition is better termed intermittent rhythmic theta activity rather than intermittent rhythmic delta activity, although the later is more commonly used. In intermittent rhythmic slow wave activity brainmapping has apparently shown that predominant middle line activity is more often down-shifted to the theta range rather than the delta range.

Because the intermittent rhythmic slow wave activity occupies the same electrode regions that are normally occupied by the alpha activity, so it looks like that both (the intermittent rhythmic slow wave activity and alpha spindles) share a common generator.

The generator (The pace maker) that is responsible for the generation of intermittent rhythmic slow wave activity is the same generator which is responsible for the generation of alpha spindles under normal conditions, however in the former condition the generator (the pacemaker) is diseased and firing at a lower rate.

In summary, although the condition is frequently termed frontal intermittent rhythmic delta activity (FIRDA) or occipital intermittent rhythmic delta activity (ORDA) in conventional EEG, however by using the brainmap technology the following are shown:

- Intermittent rhythmic slow wave activity is simply a condition where the predominant middle line activity is down-shifted from the alpha range to the theta range with maximum activity at F3, F4, FZ, O1, O2 electrode regions. During intermittent rhythmic slow wave activity the alpha spindle (as the dominant EEG activity in middle line electrodes) is replaced by slow wave spindles (mostly in the theta range rather than the delta range) which now dominate EEG activity in the middle line electrode regions.

- In frontal intermittent rhythmic delta activity (FIRDA) the maximum slow wave activity is recorded at F3, F4, FZ electrode regions by brainmapping. This pattern is more commonly seen in adult and it reflects a diffuse encephalopathic process, it is also seen in middle line tumors, parasellar and infratentorial tumors, vertebro-basilar insufficiency and migraine.

- In occipital intermittent rhythmic delta activity (ORDA) the maximum slow wave activity is recorded at O1, O2 electrode regions by brainmapping. OIRDA is found almost exclusively in children. This pattern is probably epileptiform in nature. However, this pattern does not appear to be pathognomonic of epilepsy. The 3 c/s spike/wave discharge of absence attacks is occasionally preceded by OIRDA.

- Whether OIRDA or FIRDA, the discharge is maximum in the middle line electrodes at F3, F4, FZ, C3, C4, CZ, P3, P4, PZ, O1, O2 and it replaces the alpha activity that normally reigns in these territories. The alpha activity is longer the prevalent activity at the middle line electrodes regions during intermittent rhythmic slow wave activity. Alpha activity is normally prevalent at O1, O2 and F3, F4, FZ electrode regions as well as the intermittent rhythmic slow wave activity which takes the upper hand in middle line electrodes and becomes the prevalent activity when they occur, they also retain the same characteristics of alpha spindles in spatial topography and visual reactivity.

- There is a fairly good degree of symmetry, synchrony and coherence in theta or delta percentage activity maps (during intermittent rhythmic slow wave activity). However it is not very infrequent to see some degree of asymmetry and lateralization with more theta or delta percentage activity seen on one side than the other.

References