Analysis of EEG Seizure using Fractal Dimensions by the Application of ECT Stimulus to Cerebral Cortex

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***Abstract*—** Stimulus is an external agent which produces excitability in tissues. Electroconvulsive therapy (ECT) is a form of medical treatment for severe depression, bipolar disorder and psychotic illnesses such as schizophrenia. An electroencephalogram (EEG) signal is generated from the natural currents of billion nerve cells in the cerebral cortex. Seizure occurs when there is an excessive synchronous discharge of neurons within the central nervous system (CNS). Response of the brain is high at the given point of stimulus and gradually decreases as time elapses, which can be observed as early, mid and post seizure respectively. In this paper, EEG seizure using fractal dimensions (FD) were measured and an attempt is made by comparing the FD values with the subjective conclusion taken clinically. The FD values were measured on four channels of recorded EEG during ECT by a volunteer. The fractal method is successful in detecting low amplitude spikes and the changes in the patterns of the EEG. Fractal characterization is not only an useful tool in analyzing EEG but also can be employed in analyzing and comparing various complex biological signals.

Keywords- *Electroconvulsive Therapy; Stimulus; Cerebral Cortex; Fractal Dimension; Central nervous system; Schizophrenia;*

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I. INTRODUCTION

Nervous system controls all activities of the body. The CNS includes brain and spinal cord which are suspended in the cerebrospinal fluid. Brain is situated in the skull and it is continued as spinal cord in the vertebral canal through the foramen magnum of the skull bone. The brain works through complex electrical and chemical processes. Brain is formed of two cerebral hemispheres right and left. Each cerebral hemisphere is formed of four lobes. Frontal lobe (motor area), Parietal lobe (sensory area), Temporal lobe (hearing & memory), Occipital lobe (Vision) [1].

The signal is a physical quantity which differs with respect to time, space and contains information from source to destination. The signal which is described by a continuous function is called continuous signal (speech, music signal).

Biomedical signal is a non-stationary signal whose frequency changes over time. The EEG was first measured in humans by Hans Berger in 1929. Human brain discharges the electrical impulses, which can be recorded by placing electrodes on the intact skull; these records are called as EEG.

An EEG gives a coarse view of neural activity and has been used to study the physiology of the brain noninvasively. EEG system covers all parts of brain by placing electrodes on entire surface of the scalp. The peak to peak amplitude of the waves that can be picked up from the scalp is normally 100 μV or less [2].

Electrographic seizure consists of paroxysmal events which are trains of rhythmic repetitive sharp waves as shown in the lower part of Figure 1.

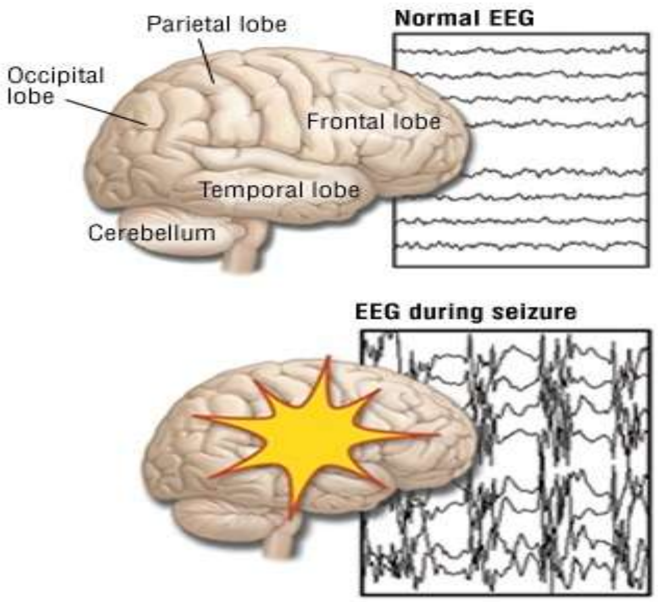

Figure 1. Comparison of Normal EEG & Seizured EEG

The common neurological disorder in which the EEG pattern is altered is epilepsy, which occurs due to excessive discharge of impulses from cerebral cortex. The disorders of mid-brain affect the ascending reticular activating system and subdural hematoma during which there is collection of blood in the subdural space over the cerebral cortex. Bipolar disorder

(Manic Depression) alternating periods of elation and depression. Brain disorder that affects the way a person acts, thinks, and sees the world is called as schizophrenia. Catatonia is a syndrome that is associated with both schizophrenia and affective (mood) disorders. It is characterized by marked changes in muscle tone or activity that may alternate between the extremes of a deficit of movement (Catatonic Stupor) and excessive movement [3].

Mania is characterized by elated, euphoric or irritable mood and increased energy. In severe manic episodes, individuals are psychotic and require continual supervision to prevent physical harm to themselves or others [3].

The frequency contents of EEG are of crucial importance in the diagnosis of neurological disorders. The frequency varies greatly with different behavioral states, and the nature of the wave varies over the different parts of the scalp whose details are provided in table I. In an EEG, the potential difference between an electrode position and its reference point is amplified and then recorded by pen writers on continuously moving paper [4].

TABLE. I WAVES OF EEG.

Wave Type	Frequency Range	Amplitude Range	Presence/Inference
Delta	< 4 Hz	20-200 µV	during deep sleep, depression, tumor, epilepsy etc.,
Theta	4 – 8 Hz	5-10 µV	Infants below 5 years of age
Alpha	8 – 13 Hz	50 µV	Occipital region of scalp, during drowsiness or light sleep
Beta	13-22 Hz	10 µV	Parietal & frontal region, during intense activation of CNS

ECT is a procedure in which a brief application of electric stimulus is used to produce a generalized seizure. ECT can be recommended in case, other forms of treatment are ineffective. Carefully-controlled electrical current is passed through the brain, affecting the brain's electrical activity and producing an improvement in depressive and psychotic symptoms. ECT is also used for some patients with suicidal tendency, who cannot wait for antidepressant medication to take effect. ECT devices are designed for user selectable AC voltage from 90 to 160 V. The current passes through brain structures between the electrodes are governed by the inter-electrode impedance that comes from the electrode-skin contacts as well as the rest of the anatomical structures. Inter-electrode impedance is variable both across individuals and within individuals across ECT sessions [5]. The current (I) and duration of time (T) yields the charge (Q) traversing through brain tissue in units of Coulombs (C) is given by the expression $Q = IT$.

The conventional sine-wave stimulus is crude, in which the slow rising and trailing edges of the sine wave do not produce efficient cerebral stimulation. Sine wave stimulus may cause an adverse effect on the patient. In order to achieve better efficacy in ECT stimulus, the sine wave was modified to eliminate the rising and trailing edges, retaining only the peaks in the form of square wave pulses. These pulses are of short duration about 1–2 ms with no stimulus in between the pulses. Intermittent stimulation using pulses are more efficient as it allows the tissue to recover from post-depolarization refractory period. Hence, the brief pulse stimulus is preferred. The stimulus sources available today evaluate the inter-electrode impedance and dynamically adjust the voltage to ensure a constant current throughout the stimulus application [5].

NIVIQURE ECT system produces pulsed, constant current, bidirectional, electronically controlled electrical charge of 30 to 540 milli-Coulombs for best therapeutic effect. This ensures just adequate electrical dosage required for the least side effects like memory impairment, post-ECT confusion, etc., Safety of medical attendants and other electro-medical/electronics apparatus in contact with the patient at the time of ECT administration are ensured by using surge protection circuit [6] and isolation techniques.

Features of NIVIQURE ECT system are Auto-set electrical dosage, off-line or on-line data recording, retrieval, automatic dosage setting based on gender, age, post ECT-EEG display, recorded storage, printer output for recording purposes, number of channels selectable either 2 or 4.

FD's are the mathematical concepts which measure geometrical complexity of a given signal. Katz algorithm is the most appropriate technique for complex biological signal analysis as compared to other FD methods. Therefore, it estimates the fractal dimension that is a numerical value which is useful for the signal analysis in time series for the specific problem. FD is an attractive analytic approach as it allows detection of subtle waveform abnormalities.

II METHODOLOGY

Detailed methodology employed in this work is described in the subsequent sections.

A. Calibration of EEG amplifier

Calibration is essential to know the performance of EEG amplifier. A known test signal of 10 Hz with a trough to peak voltage of 100 µV is applied prior to the recording of an EEG signal. Removing baseline drift means making zero mean correction. It is often observed during EEG recording that the signal obtained begins to stay away from the baseline which is the iso-electric line. Removing baseline drift involves calculating the mean of the signal and then re-plotting every point of the recorded EEG signal.

B. Data acquisition

The patient was instructed to close both eyes during the data acquisition period after accomplishing preparatory medications. Electrodes were placed according to the

American International standard 10-20 EEG electrode system [7]. Built in EEG amplifier in ECT machine has the gain of 1000. To remove artifacts and noise, low pass filter as well as high pass filters were employed. The narrow band reject filter, often called the notch-filter, is commonly used for rejection of a single frequency such as 50 Hz power line frequency hum.

EEG signals were recorded from the patients suffering from mental disorders as per existing standard techniques. Four channels of unipolar electrodes were placed on right frontal (RF), right temporal (RT), left frontal (LF) and left temporal (LT) regions respectively. The EEG signals from the patient were recorded for duration of a 155 seconds [8].

EEG signals thus recorded were digitized using ADC (256 samples/second per channel). After digitization process quantification of EEG data of a patient suffering from either schizophrenia or bipolar disorder was carried out to obtain an objective diagnosis.

C. Filtering of EEG signal using digital filter

Raw EEG signals were filtered by using finite impulse response (FIR) low pass filter of order 40. FIR filter provides linear phase and always stable. The design method is generally linear, order required for FIR filter is higher and the filter start-up transients have finite duration [9].

FIR filter of length M is described by the difference equation which is given below:

$y(n) = b_0x(n) + b_1x(n-1) + b_2x(n-2) + \text{- - - - - --} + b_{m-1}x(n-m+1)$
$y(n) = \sum b_k\, x(n-k)$ between the limits k=0 to (M-1).
where
b_k is the set of filter co-efficients.

The response of the FIR filter depends only on present and past input samples. Linear characteristics within pass band are achieved by FIR filter. In the present work, following specifications are considered based on the desired response.

M = 40; Cut off frequency ω_c =32 rad/s;
$\tau = (M-1)/2$
τ = Phase delay
$h(n) = \text{Sin}\{\omega_c (n-\tau)\}/\pi(n-\tau)$
where
h(n) is the transfer function of the filter
where
n = 0 to (M-1).

The patient data acquired from NIVIQURE ECT system in the ECT laboratory x(n), is convolved with h(n) to obtain filtered out put as y(n).

$y(n) = x(n) * h(n)$
$y(n) = \sum x(k)\, h(n-k)$ for k = 0 to (M-1)
where
n - length of the input signal x(n).

D. Computation of fractal dimensions:

The FD is represented by an individual number (often a fraction) that can be used as a fundamental quantification of even the most complex signal [10].

FD for planar curve $D = \text{Log}(L) / \text{Log}(d)$
where
L - total length of the curve,
d - diameter of the curve
L = sum [dist (i, i+1)]
i.e distance between two point pairs
d = max [dist (1, i)]
i.e. average distance between successive points using average step ‘S’

In the present work there is a need to analyze recorded complex biological signals which render FD unsuitable for planar curve. Therefore, FD for the analysis of recorded EEG seizure is estimated using Katz algorithm.

$FD = \text{Log}(n) / \text{Log}(n) + \text{Log}(d/L)$
where
n = L/S is the number of steps in the curve.

Digitized EEG data were used to compute FD by logarithmic transformation [10].

III RESULTS AND DISCUSSION

The EEG signals recorded with afore mentioned regions are as shown in Figure 2 with four channels (RF, RT, LF & LT) respectively contains around 37000 samples.

Figure 2 shows complete recording of EEG seizure during ECT. Figure 3, 4 and 5 are the early, mid and post seizures selected on the basis of clinical interest with separate four channels. The early phase of seizure is the first 8 second data soon after the stimulus offset, mid-seizure is a part of the seizure EEG with maximum amplitude and the post-seizure is the first 8 second data after the end of seizure. Seizure termination is a clinical judgment of absence of all seizure discharges.

It is evident from Figure 6 that at the beginning of early, mid, and post seizures the FD values are high in all four channels respectively. Also, Figure 6 depicts that fractal values are abruptly changing at different points and these FD values are depending on the EEG signal characteristics (amplitude and time). As time elapses FD values having a tendency to detrend with respect to time and can be observed in Figure 6. In general, FD values for any complex biological signals are to be in the range 1 and 2. In the present work, the FD values in all three types (early, mid and post seizures) computed across four channels are also lie between 1.1 and 1.3 which can be seen from Figure 6.

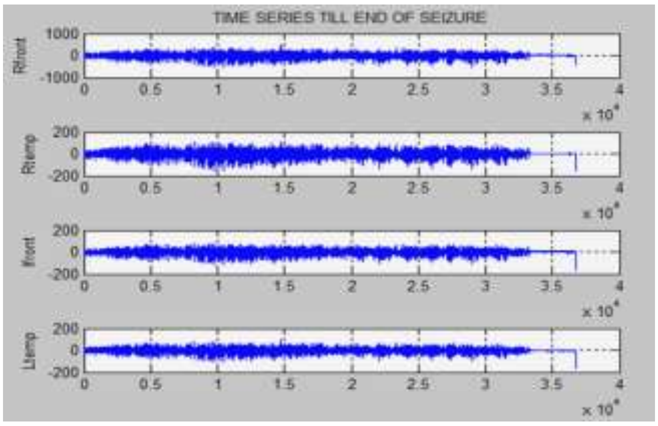

Figure 2.Time series till end of seizure

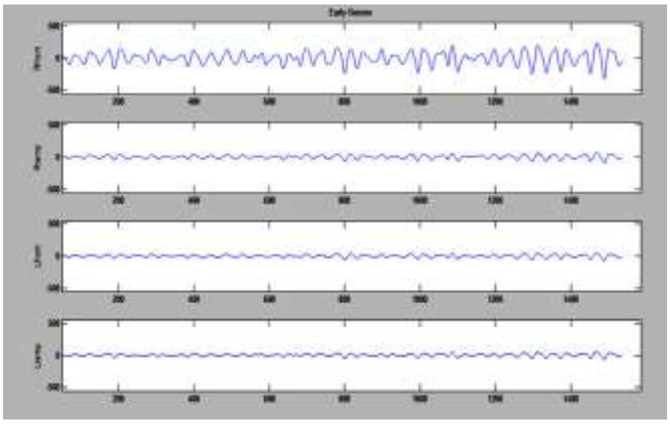

Figure 3. Early Seizure

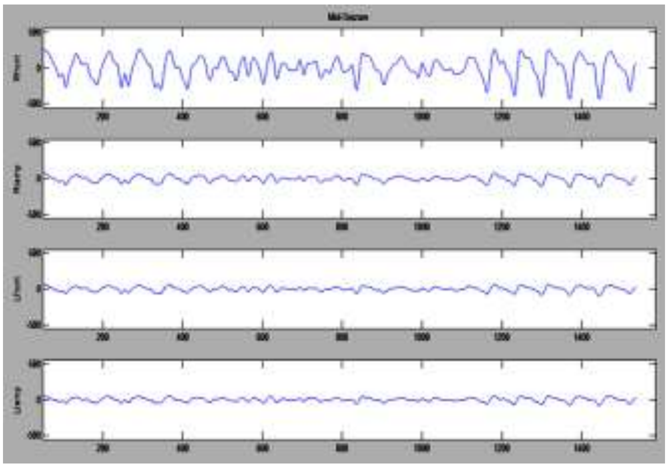

Figure 4. Mid Seizure

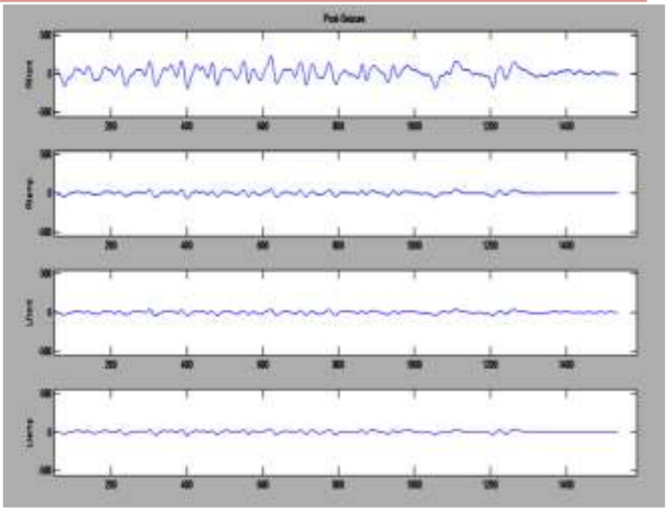

Figure 5. Post Seizure

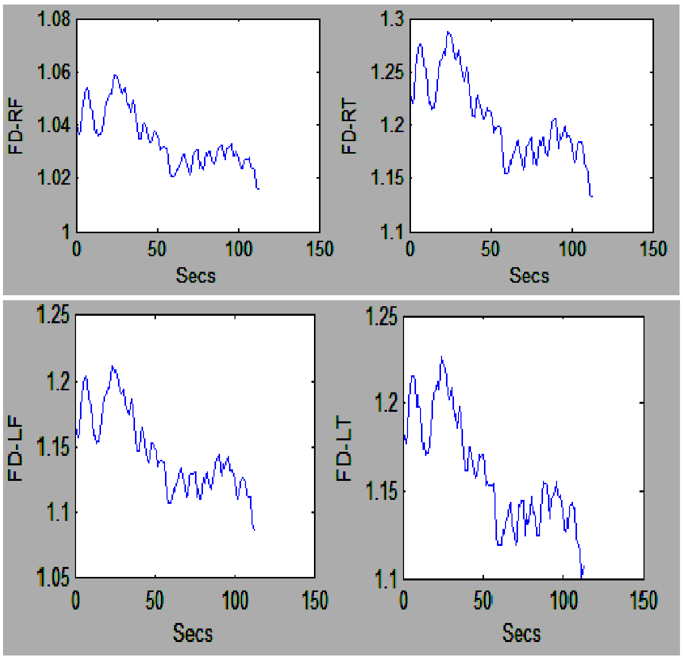

Figure 6. Fractal Dimensions plot

IV CONCLUSION

The FD values rise from early to mid-seizure falling abruptly in post seizure. Smaller FD value in the post seizure could reflect post-ictal suppression. This smaller magnitude post seizure FD values are considered by a neuro-physician as the recovery of patient from mental illness.

The ECT is effective in improving depressive and psychotic symptoms. The seizure causes activation of neurons throughout the brain and changes many of the chemicals in human brain. It is thought that these actions then result in reduction of symptoms of mental illness. The clinical applications of FD are more significant, if they are interpreted more accurately and effectively.

The present study suggests that FD may be an effective method of presenting large scale EEG data in a comprehensive single line plot. FD is useful to detect low amplitude spikes in complex waves and it gives EEG signal structure thus helping in the diagnosis of neurological disorders. The FD values provide a quick geometrical measure for EEG seizure analysis during ECT.

For each session, the highest values of FDs were noted visually using the FD graph. The average of these for each seizure EEG was used for comparison across ECT sessions. This study shows that the maximum FD remains virtually constant through a course of ECT irrespective of the ECT electrode placement and contrary to the duration of seizures.

In routine clinical practice, ECT interpretation is based on visual inspection of EEG seizure induced due to ECT is not only subjective in nature, but it also depends on observational variations regarding seizure EEG. FD technique overcomes the above drawbacks and FD values are quantifiable within the range 1 and 2. Therefore, it is more reliable than conventional and enables the psychiatrist in early therapy planning.

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