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Cumulative power spectrum of EEG-a predictor of awake and sleep state

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ABSTRACT : Anaesthesia administration during surgery is a demanding task. It requires complete knowledge about the exact sleep state of the patient. However, accurate judgement of the patient's exact state has been a problem faced by anaesthesiologists for years. Till date several electroencephalogram (EEG) parameters have been computed which form the index to indicate the unconsciousness of a patient. Efforts are still continuing to find out parameters with better accuracy in prediction, high repeatability & reproducibility of results and drug independence. A recently discovered parameter from EEG Signal, the cumulative power spectrum (CPS) promises a significant improvement over the existing parameters with higher correlation with awake and sleep state of the patient. This paper focuses on the comparison of the CPS of the awake and sleep states and analyses it with respect to the frequency components in the signal.

After analysis, results show that when the patient is in the awake state, the lower frequency components have high power whereas in the sleep state the lower frequency components have comparatively low power. Thus from the cumulative power spectrum plots, one is able to judge the degree of unconsciousness of the patient accurately. The judgement is confirmed by comparing it with a characteristic EEG index which has unique values for the awake and sleep states.

Keywords : Depth of Anesthesia, EEG, Cumulative power spectrum, Awake and Sleep state

I. INTRODUCTION

Approximately seven million surgeries are performed per day worldwide and in each one of them, a basic necessity is the efficient administering and control of anaesthesia. Aim is to provide a safe surgery with maximum patient comfort. However, administering the anaesthesia drug is a complicated procedure and needs to be done carefully while insufficient quantity of the drug may result in awareness during surgery, excess of it may land the patient into coma. Hence it is essential to continuously monitor and control the quantity of anaesthetic drugs given to the patient.

Response to anaesthetic drugs vary from person to person depending upon his health (illness), age, gender etc [1]. A certain amount of drug may drive a person into deep sleep whereas the same amount may be inadequate for another. The obstacle in monitoring the state of a person is the fact that anaesthesia shuts down both sensory and motor responses of the person simultaneously. There have been instances where the amount of anaesthesia administered has been sufficient to shut down the sensory system (the patient feels no pain) but the motor systems were active (he still moves his limbs). An anaesthesiologist has to put in lots of effort to control the exact quantity of anaesthesia administered to a patient.

Before administering the drug, it is necessary to find a relation between the exact state of patient and the amount of anaesthesia given to him/her. As it is difficult to monitor involuntary movements, the most common technique is to monitor the state of the brain. This is achieved through the analysis of Electroencephalogram (EEG). There are some general features that characterize the effect of anaesthetic drugs on the EEG [2,3]. However, it is difficult to identify the patterns corresponding to a particular level of anaesthesia by viewing the EEG signal. There are number of EEG parameters which can be used to determine the relation between the depth of anaesthesia and the state of a patient [4-6].

A recently discovered parameter called the Modified Cumulative Power Spectrum (MCPS) of the EEG signal promises a significant improvement over the existing parameters in terms of accuracy in prediction and correlation with the awake and sleep state of the patient. Observation of the cumulative power spectrum plots easily enables one to determine quite accurately the state of sleep of the patient.

II. MATERIALS AND METHODS

After approval from the Hospital ethics committee, EEG signals of eight different patients under halothane-nitrous oxide-oxygen anaesthesia were obtained. The demographic details of the patients are given in Table 1. These patients underwent gynaecological surgery of durations ranging from 30 minutes to 2 hours.

Table 1 :

Patient No.	Gender	Age (Years)	Weight (Kg.)	Height (m)	Body Surface Area	Type of Surgery
1	F	41	67	1.55	1.66	Gynaecology
2	F	29	46	1.44	1.34	Gynaecology
3	F	52	78	1.32	1.57	Gynaecology
4	F	30	72	1.47	1.65	Gynaecology
5	F	56	56	1.67	1.62	Gynaecology
6	F	21	68	1.72	1.80	Gynaecology
7	F	45	82	1.54	1.80	Gynaecology
8	F	23	60	1.60	1.62	Gynaecology

A. Procedure of anaesthesia infusion

Without any premedication, anaesthesia with halothane was introduced though a face mask. The trachea was intubated and the lungs ventilated mechanically with nitrous oxide-oxygen mixture containing 30% oxygen. The end tidal concentration of halothane was maintained at 0.75% for 10 minutes which is sufficient to make the patient anesthetized. Muscle relaxation was achieved by 0.1 mg/kg vecuronium. Patients were also monitored by a standard 3-lead EKG and a peripheral pulse oximeter. Oesophageal temperature was held between 36 and 37 degrees. Ventilation was controlled to maintain end tidal CO_2 between 35 and 40 torr. SpO_2 was normally greater than 98%. No opioid was administered during the observation. The state of sleep of the patient was tested by asking them to hold the investigator's hand every 60 seconds. Any physical movement to this command confirmed the awake state and no response confirmed the sleep state.

B. EEG monitoring and data acquisition

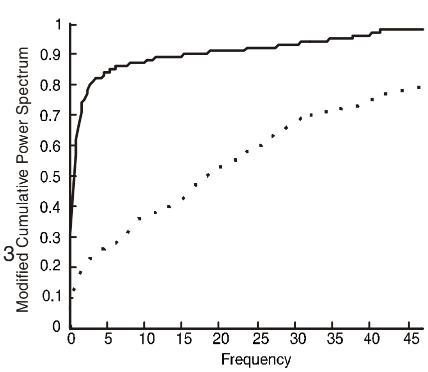
Four cup type Ag-AgCl electrodes (Recorders & Medicare systems, India) were used to obtain the EEG signals. They were placed at middle forehead F_{pz} (ground), C_z (reference), F_p1 and F_p2 according to international 10-20 system of electrode placement. The dual channel EEG signal was recorded by a computerized machine (Recorders & Medicare systems, India). The signal was digitized at the rate of 256 Hz with a 12 bit A/D converter and stored.

C. Extraction of the cumulative power spectrum

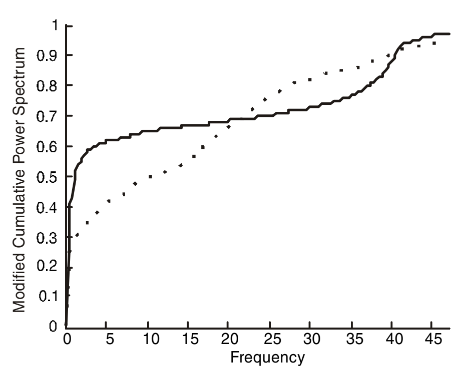
The stored signal was divided into 4 second epochs and each epoch corresponded to a segment of the EEG signal. Artefacts such as eye-blinks (characterized by negative peaks of high amplitudes in the EEG signal), power line noise etc were removed [7]. The signal was then subsequently passed through a low pass filter with cut off frequency 47 Hz. Next, the Fast Fourier Transform (FFT) was applied to each segment to convert it into its frequency domain. Finally the power spectrum of each segment was obtained.

The power spectrum of each segment was then divided by the average power spectrum of all the segments for that particular patient. The purpose of this being to remove the common content from each segment. The cumulative power is computed till the frequency of 47 Hz for each segment and divided by the total power of that segment. This is done in order to make the indexing of the spectrum range from 0 to 1. This is called the Modified Cumulative Power Spectrum (MCPS) and forms a basis for our separation of the awake and sleep states.

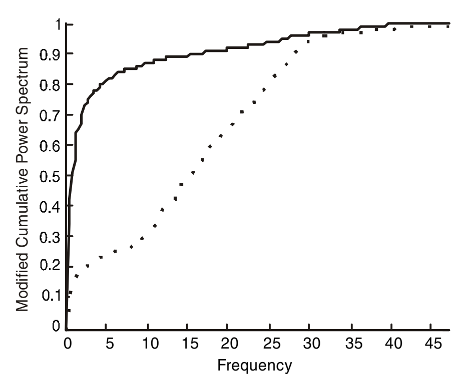
D. Separation of awake and sleep states based on the MCP



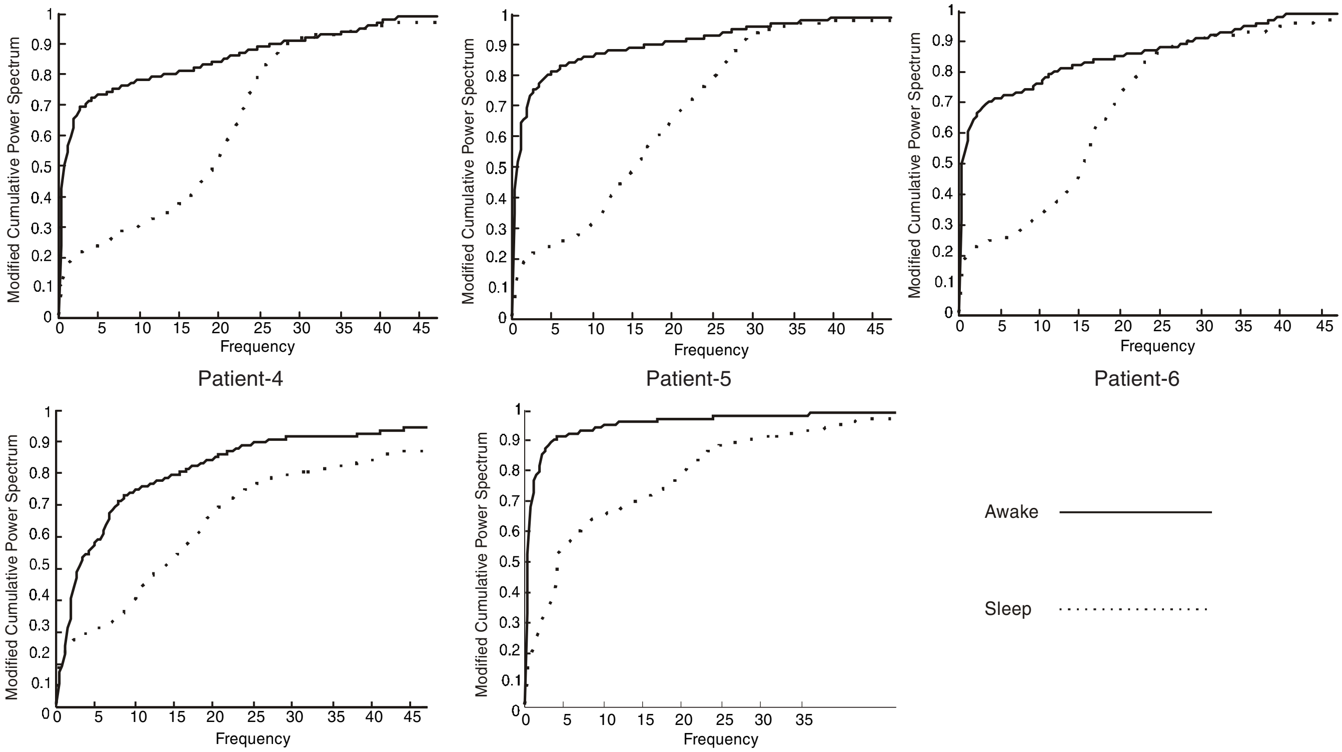
Patient-1



Patient-2



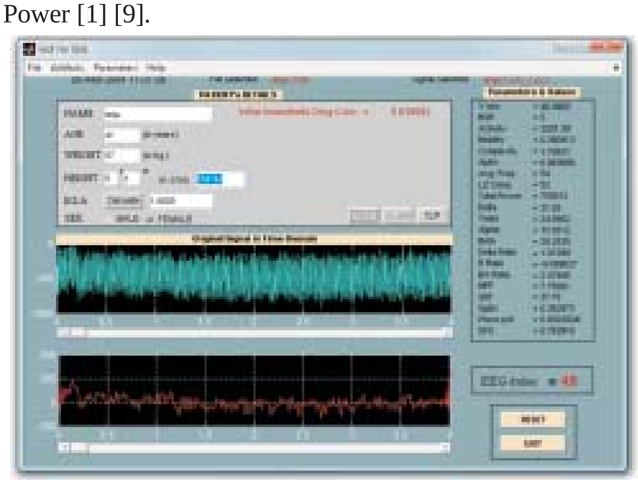
Patient-3



III. RESULTS AND DISCUSSION

After plotting the MCPS of all the patient indecently, it is observed that during awake state lower frequency components has high power whereas on the other hand, during sleep state lower frequency components has comparatively low power. A clear distinction between the sleep and awake state occurs in the plots.

The obtained MCPS plots were compared with a characteristic EEG index [8] obtained from 5 different EEG parameters out of 21 parameters namely Average Frequency, Approximate Entropy, LZ Complexity, Delta Power and Beta Power [1] [9].



The awake state epochs were characterized by an EEG index value of 84-87 whereas the sleep state epochs were characterized by a EEG index value of 45-49. This showed that the MCPS plots are in consistence relation with the EEG index and clearly provide a separation between the awake and sleep states of patient.

Going further, by plotting the MCPS curves for all the patient in awake and sleep state with respect to different frequency ranges of the EEG signal, it is observed that during awake state the rate of change (slope) of MCPS curves is steep in the Delta range (0-3Hz) where as gradual in sleep state in the Delta range. On the other hand during the sleep state the slope is steep in the Beta range (12-26Hz) whereas gradual in the awake state in the Beta range as shown in Fig.1 below.

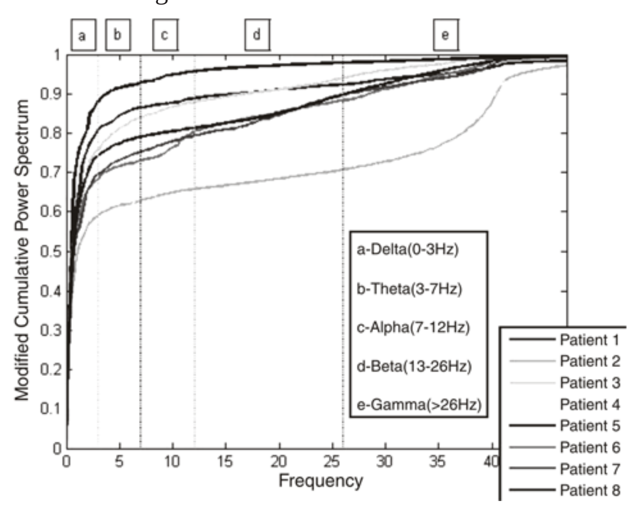


Fig.1. Awake State MCPS plots of the 8 patients.

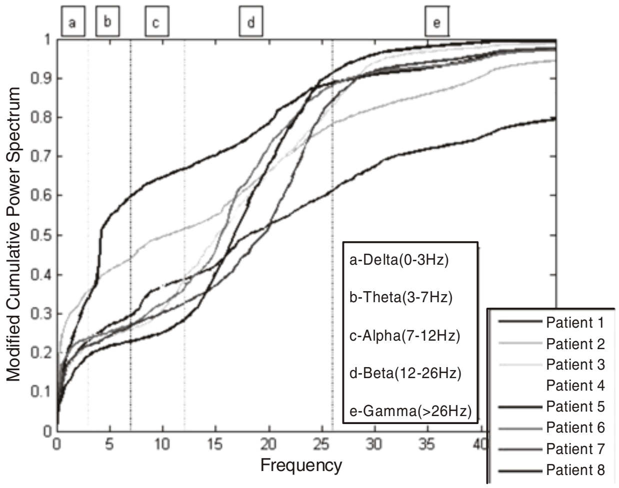


Fig.2. Sleep state MCPS plots of the 8 patients.

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