Development for the Evaluation Index of an Anesthesia Depth using the Bispectrum Analysis

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Abstract—The linear SEF (Spectral Edge Frequency) parameter and spectrum analysis method can not reflect the non-linear of EEG. This method can not contribute to acquire real time analysis and obtain a high confidence in the clinic due to low discrimination. To solve the problems, the development of a new index is carried out using the bispectrum analyzing the EEG(electroencephalogram) including the non-linear characteristic. After analyzing the bispectrum of the 2 dimension, the most significant power spectrum density peaks appeared abundantly at the specific area in awakening and anesthesia state. These points are utilized to create the new index since many peaks appeared at the specific area in the frequency coordinate. The measured range of an index was 0-100. An index is 20-50 at an anesthesia, while the index is 90-60 at the awake. New index could afford to effectively discriminate the awake and anesthesia state.

Keywords—Bispectrum, anesthesia depth, EEG, SEF.

I. INTRODUCTION

THE anesthesia is composed of unconsciousness, analgesia (pain relief), amnesia (loss of memory) and immobilization. However, the anesthesia can be, in general, defined as a state of drug-induced unconsciousness in which the patients neither perceive nor recall the noxious stimulation [1],[2]. It has profound effects on a patient's physiology due

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to the general effects on central nervous system as well as specific effects on all other body systems [3]. Thus, anesthesia is essential to prevent pain or distress in patients. But some patients are inclined to have uncomfortable experience due to the awakening with or without pain during anesthesia. It is indispensable to evaluate the depth of an anesthesia during a surgical operation not to be influenced from it [4]. There have been immense researches in medicine, especially in the field of an anesthesia to seek the safe anesthetic level. Bickford [5] et al studied the compressed spectral array(CSA) to estimate the depth of an anesthesia using the change of the frequency of the EEG in general anesthesia. Sigl and et al [6] also developed the index appearing the depth of anesthesia by using the bispectrum method which is one of the non-linear methods in the EEG analysis. Thereafter, the bispectrum index system was developed to estimate the depth of an anesthesia. Especially, the assessed index is useful tool in estimating the sedation. Bipsectrum analysis, one of the high order spectrum methods revealing non-linear characteristic of EEG, has widely utilized in the research on the depth of anesthesia. In this paper, we verified the validation of SEF and the limitation to the clinical application among analysis parameters of EEG spectrum during the operation. The new parameters are developed to overcome the limit of a clinical application. The validation of the index is verified using an acquired parameter through the bispectrum analysis. The change was observed in the 2D map by producing the data analyzed through bispectrum analysis. A high 10 peaks indicating maximum PSD (power spectrum density) in the interval of every 2 second was stored and then the significance on distribution of peak appearance was observed through classifying the appearance frequency of whole peaks into awakening and anesthesia. Based on the distribution of the total peaks, the sum of awakening points was calculated after extracting and index calculation were accomplished after extracting 10 points with maximum amplitude at the anesthesia and awake. The new index was also accomplished by comparing the PSD sum of the points during an anesthesia.

II. ANALYSIS OF THE EEG

The preprocessing such as base line correction and linear detrend widely used in biomedical signal processing was used for measured brain wave. Base line correction was utilized to eliminate the offset voltage included in the measured signal. On

the other hand, linear detrend was used to remove the increasing or decreasing signal values due to the changing resistance resulting from the long term attachment of the electrode and the perspiration. In case of analyzing the brain wave using PSD, the general method in the signal processing, the depth of anesthesia can not be evaluated effectively. Accordingly, the depth of anesthesia was utilized by the secondary parameter in cooperating with other features of EEG signal during an anesthesia in the clinic field. The basic principle to create the parameter is on the basis that EEG signal reveals comparatively low frequency (below 8Hz) when the brain is in stable and sleep state, while that shows high frequency(above 8Hz) when the brain is in active state. In the light of center nervous system, an anesthesia has the EEG mechanism in similar to sleep. Accordingly, like sleep state, the slow frequency wave below 8Hz increases in the progress of anesthesia. In the light of sleep, the parameter formed on the base that the compositional rate of slow frequency wave below 8Hz and high frequency wave above it is changing according to the stability. It is reasonable to extract parameters for specific factor while interpreting a state of brain such as the change of detail consciousness and change of sedation, new parameter to distinguish the depth of anesthesia was developed by comparing SEF connecting with the sedation level of patients and the bispectrum parameter realized in this work. The definition of SEF was defined as the frequency at which the accumulated sum of lower frequency spectrum exceeds 95% of total power spectrum. The index of the anesthesia depth in EEG was evaluated using the criterion of these parameters.

A. Method of Bispectrum Analysis

Bispectrum analysis is defined as 2D FFT. EEG signal reflected the non-linear peristalsis phenomena according to the change brain function. Even though PSD widely used in biomedical signal processing is very useful analysis method, this technique can not afford to give the phase information.

On the other hand, the bispectrum and the bicoherence provide the information regarding the signal characteristic without excluding valuable information in biomedical signal processing.

To define the bispectrum, first takes the original time series data h_{lk} and split it into L segments. where L should be a power of 2. Let h_{lk} denote the k_{th} element of the l_{th} subsegment. Take the Fourier transform of each of these subsegments; now, $\tilde{h}_{ij}$ is j_{th} is element of the Fourier transform of the l_{th} subsegment. The bispectrum is then defined as:

$$B(j,m) = \frac{1}{L}\sum_{l=0}^{L-1}\tilde{h}_{lj}\tilde{h}_{lm}\tilde{h}^*_{l(j+m)}$$

(1)

The bispectrum is a complex quantity that measures the magnitude and the phase of the correlation between the phases of a signal at different Fourier frequencies.

Thus, a signal containing multiple frequencies that are related to each other, such as the orbital frequencies of a body around a black hole, show interesting bispectral structure.

The bicoherence is a related quantity that has the vector magnitude of the bispectrum, normalized to lie between zero and one. It is defined as:

$$b^2(j,m) = \frac{\left|\sum \tilde{h}_{lj}\tilde{h}_{lm}\tilde{h}^*_{l(j+m)}\right|^2}{\sum \left|\tilde{h}_{lj}\tilde{h}_{lm}\right|^2 \sum \left|\tilde{h}_{l(j+m)}\right|^2}$$

$$= L^2 \frac{|B(j,m)|^2}{\sum \left|\tilde{h}_{lj}\tilde{h}_{lm}\right|^2 \sum \left|\tilde{h}_{l(j+m)}\right|^2}$$

(2)

Note that all sums in this equation run from = 0 to L-1.

III. Experiment Method

After obtaining approval by the ethics committee and informed written consent, we studied 12 ASA I or II adult patients. Patients with history of dementia and neurological disorder are excluded. EEG signal is sometimes unstable in case of young child. Therefore, adults above 15 years old without mental rejection to a brain wave were selected as research objects.

The stage Anesthesia is classified into 3 stages in which there are the preoperative stage, operative stage and postoperative stage respectively. Anesthesia during the operation was progressed in accordance with an oral command of attending anesthetist. Measurement of EEG was acquired and the process of anesthesia was recorded simultaneously.

EEG recording of preoperative must be acquired immediately after patient's arriving at the operating room. But it is reasonable to treat the time just after arriving at the operation room as the induction stage of anesthesia which is usually within 5 minutes. Only a few data can be obtained within short period because of an apparent limitation of time. As a whole, the induction for operation starts immediately after patient is carried to the operating room. It is difficult to acquire the reliable EEG data due to pre-medication. For this reason, preoperative data was acquired in the previous day before operation day.

For patients at the stage of awakening, the data was acquired in the next day after operating because of disturbing factors such as a hand trembling at recovery stage

The Ag/AgCl electrode, disposable and stick-on electrode to attach effectively, was used for electrode. According to 10-20 system of electrode placement for EEG recording recommended by the International Federation of Societies for Electroencephalography and Clinical Neurophysiology, actual measuring electrode were attached on 3 spots of the frontal, ground and an earlobe reference electrode. The name 10-20 indicates that the electrodes along the midline are placed at 10, 20, 20, 20, 20 and 10% of the total nasion-inion distance: the other series of electrodes are also placed at similar fractional distances of the corresponding reference distance. The inter-electrode distances are equal along any anterior-posterior or transverse line, and electrode positioning is symmetrical.

A. Measurement for EEG and Analysis Method

Frequency band for EEG analysis is generally below 100Hz. SEF and MF parameters used to estimate the depth of anesthesia is below 35Hz without influencing 60Hz notch filter. Acquisition of brain wave was acquired at sampling rate of 256 Hz using Physiolab 800 Bio-amp which measures EEG, Plethmograph and ECG simultaneously. Measurement was carried out using 8 channel NI DAQ500(12 bit resolution) A/D convert with filter set-ups of 35Hz for LPF and 1 Hz for HPF, and gain set-up of 100K. Data was acquired in the interval of every 5 sec., and data on bipsectrum and SEF was analyzed in 10 sec. including overlapped 5 sec. Bispectrum map of 2D and 10 maximum PSD points was stored and analyzed to extract the index in order to compare with SEF.

IV. RESULT

A. Spectrum Analysis

Fig. 1 indicates the result of SEF representing a significant change according to anesthesia. SEF was about 27-28 at the awakening and about 19-24 during anesthesia. SEF was confirmed to be useful index to estimate the depth of anesthesia.
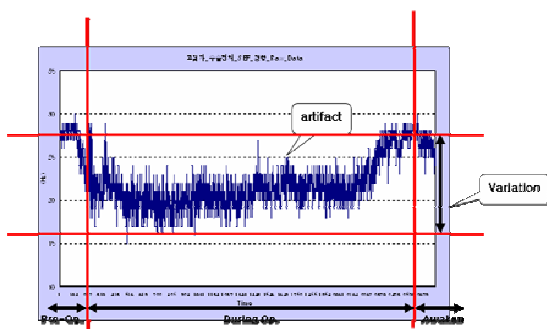

Fig. 1 The variation of SEF during the anesthesia

Fig. 2 indicates the moving average of data shown in Fig. 1 for 60sec. The curve revealed smoother and clearer, compared to the curve shown in Fig. 1.
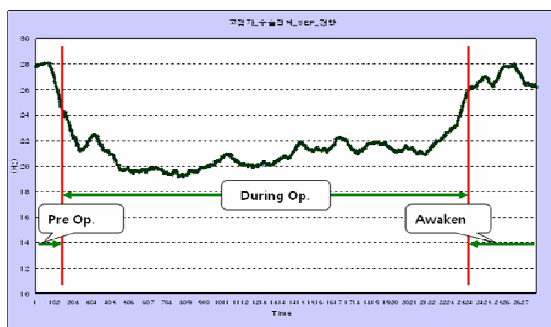

Fig. 2 The variation of the moving average of SEF during the anesthesia

Table I shows maximum, minimum, and standard deviation value of the SEF during anesthesia. The result of analysis 12 patients described above confirmed that SEF was about 28 at the pre-operation and awake and was about 19-24 at the anesthesia. However, the index variance between anesthesia and awakening, for most patients, was within 4 and, the narrowest value is 2.2, indicating extremely low discrimination.

As SEF has a low discrimination and doesn't reflect the nonlinearity of EEG, it can't obtain a high confidence in the clinic. Therefore, SEF has not been used in real time index yet.

TABLE I
MAXIMUM AND MINIMUM VALUES OF SEF

	Patient	Min.	Anesthesia Average.	Max.	Awake Average.	Variation
1	A	21.18	23.61	28.07	27.71	4.10
2	B	20.53	22.74	27.33	26.97	4.23
3	C	20.87	23.83	28.82	27.92	4.09
4	D	21.90	24.40	28.37	26.55	2.15
5	E	20.43	23.32	28.17	27.98	4.66
6	F	20.52	22.96	28.38	27.53	4.57
7	G	22.02	23.81	28.12	27.33	3.52
8	H	22.03	23.78	28.17	27.81	4.03
9	I	24.43	27.31	31.65	29.53	2.22
10	J	21.23	23.67	27.75	26.90	3.23
11	K	20.20	23.24	28.75	26.99	3.75
12	L	19.173	22.10	28.15	26.97	4.87
	Total	21.21	23.73	28.48	27.51	3.78

B. Bispectrum Analysis

Bispectrum analysis was used to reflect the nonlinear feature of EEG. It was performed in real time for per 5 sec. The result was displayed by 2D map. 2D map according to anesthesia was well observed to reveal the anesthesia process such as preoperation, during anesthesia and awakening as shown in Fig. 3. Small squares in Fig. 3 indicated the bispectrum analysis per 5 sec. The data was represented in 10 sec. in 2D map, in which data was overlapped by 5 sec., indicating the data of 125sec.

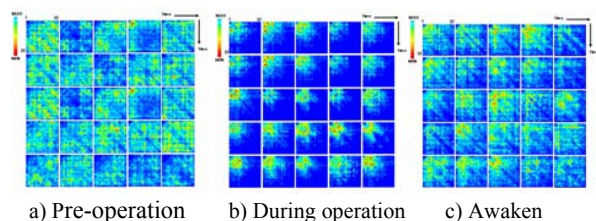a) Pre-operation   b) During operation   c) Awaken

Fig. 3 Bispectrum analysis during anesthesia

The distribution of PSD was entirely appeared at the entire range of 1-32 Hz at the awakening state prior to pre-operation. Peak of thick red mainly appeared at above 10, 10 Hz. PSD

distributions were concentrated on the range of 1-15 Hz during operation. Also, Main peak represented by red color was concentrated within 10, 10Hz. At awakening state after operation, PSD distribution appeared in the whole range of 1~32Hz, which was similar to it at awakening state before operation. To describe quantitatively the distribution change of the PSD, 10 main peaks represented by thick red was stored at each stage during bispectrum analysis. The unique characteristic was observed since significant peak appeared at the same position among experimental patients. As a result, the depth of anesthesia was evaluated using peak appearance information to extract the index.

Fig. 4 shows the sum of 10 maximum peaks. The positions were showed by 12 persons at Table II.
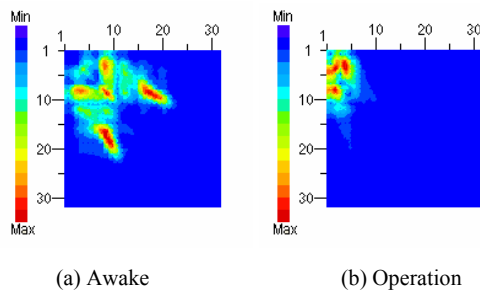

(a) Awake   (b) Operation

Fig. 4 Sum of the peak appearance rate

TABLE II
THE COORDINATES OF AWAKEN AND ANESTHESIA STATE

Num.	Awaken	Anesthesia
1	2, 2	8, 8
2	2, 3	9, 9
3	2, 4	8, 17
4	2, 8	9, 17
5	2, 9	9. 18
6	3, 3	9, 19
7	4, 2	17, 8
8	4, 3	17, 9
9	4, 4	18, 9
10	4, 5	19, 9

The main positions effected at the anesthesia were extracted. The information of the peaks was illustrated at Table II. Awakening state means both pre-operation and after operation.

Using PSD distribution, main point and frequency point representing awakening and anesthesia state were indicated at Table II and Fig. 5. Since the extracted points represent the highest PSD, the index reflecting anesthesia state could be used by comparing PSD values of reflecting the anesthesia and awakening state.
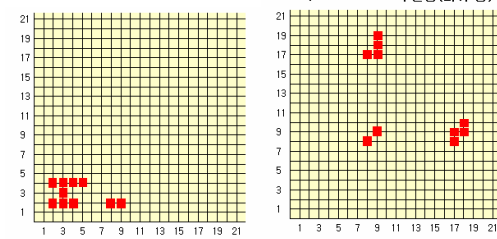
(a) Points of awaken   (b) Points of anesthesia

Fig. 5 Peak points of awake and anesthesia

PSD value was selected at these positions and the value was normalized to 0-100 as shown in Fig. 6.
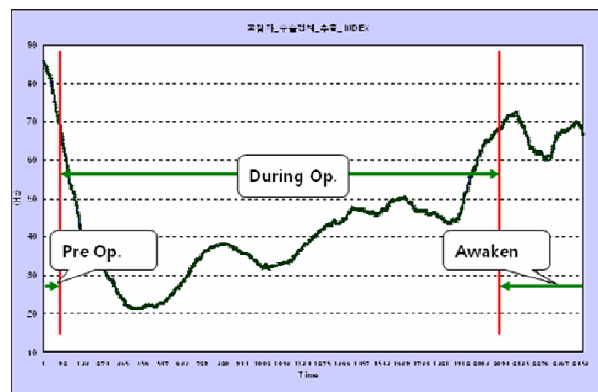

Fig. 6 Evaluation index of an anesthesia depth using the bispectrum analysis

The index of the depth of anesthesia extracted from the signal of 12 patients indicated that 60-90 was observed for awakening state and 50-21was observed for anesthesia state.

V. CONCLUSION

Even though SEF parameter based on spectrum analysis which is linear analysis method is useful in some level, it has inadequate characteristic in real time analysis because of the instability of signal without nonlinearity of brain wave. Moreover, there is no a high confidence in clinical field due to low discrimination. The development of new index through the bispectrum analysis capable of representing the linearity of brain wave was attempted to overcome these problems. The benefit of bispectrum analysis was verified by confirming the appearance of specific phase at each stage of anesthesia through 2D map. The data of uppermost PSD distribution was collected simultaneously to develop the real anesthesia index.

Analyzing acquired data from 12 patients, higher rank PSD was confirmed to be specially discriminated as two states of an awakening state (before and after operation) and an anesthesia state (mid-operation). 10 frequency points of main peak indicating these characteristic was selected to generate an index. Frequency point specially appearing lot of peaks was used as

basic data of producing an index. An index values were represented in the range of 0~10. As a result, the index within 20 ~ 50 was extracted from patient during an anesthesia, while an index above 90~60 was selected from patient after recovery.

In conclusion, through an additional research and analysis, it is indispensable to extract index with regard to patients with various medication and operation in order to verify the availability of distinctive index for the state of an awakening and an anesthesia.

REFERENCES

[1] Jeleazcov C, Fechner J, Schwilden H.,"Electroencephalogram monitoring during anesthesia with propofol and alfentanil: the impact of second order spectral analysis", *Anesth Analg*, vol. 100, pp. 1365-1369, 2005.

[2] Jeleazcov C, Schwilden H., "Bispectral analysis does not differentiate between anaesthesia EEG and a linear random process [in German]", *Biomed Tech (Berl),* vol. 48, pp. 269-274, 2003.

[3] C. Thornton and R.M. Sharpe, "Evoked responses in anaesthesia", *British Journal of Anaesthesia*, vol. 81, pp.771-781, 1998.

[4] Sandin RH, Enlund G, Samuelsson P, Lennmarken C, "Awareness during anaesthesia: A prospective case study", *Lancet*, vol. 355, pp. 707-711, 2000.

[5] Faulconer A jr., Bickford RG., "Electroencephalography in anesthesiology", *Springfield, Illinois; Thomas*, 1960.

[6] Sigl JC, Chamoun NC, "An introduction to bispectral analysis for the EEG", *J Clin Monit.*,vol. 10, pp. 392-404,1994.

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