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TRAUMATIC BRAIN INJURY LESION LOCATION ANALYSIS BASED ON EEG POWER USING FFT AND WELCH'S METHOD

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Traumatic brain injury (TBI) is an injury that may damage the brain tissue due to trauma. The injury may be observed by looking at its functional capability i.e. the brain wave. Electroencephalography (EEG) is an instrument capable to record and examine this brain signal to determine if there is any abnormality or not. One of many parameters that can be measured from EEG signal is its signal power that can be extracted by using a mathematical transformation. This study tries to analyze the power spectrum difference between the locations of brain damage in TBI cases by using an intracranial-electrode equipped EEG. The comparison is made with fast Fourier transformation (FFT) and Welch's method to determine a better measurement method. The results show that both methods are capable to differentiate lesion locations in four of five TBI cases, but exhibit no superiority to each other.

Keywords :EEG; traumatic brain injury; signal power; fast Fourier transform; Welch's method

INTRODUCTION

Traumatic brain injury or TBI is an alteration in brain function or other evidence of brain pathology that caused by an external force [Menon, D. K.,et al 2011]. This injury may results from a direct source such as skull puncture or an indirect one like a concussion. The severity is divided into three categories of mild, moderate, and severe depends on patient's signs and symptoms that correlate with tissue damage. Mild injury usually resides within benign condition with Glasgow Coma Scale (GCS) measurement range from 13 to 15, meanwhile a moderate injury has GCS range from 9-12 [Silver J.M. et al, 2005].

To find any difference between locations of an injured brain, we may decide this by looking at its physiological capacity. The changes that occur in brain tissue may be observed by its brain signals that can be recorded by using electroencephalography (EEG). EEG is a standard, non-invasive instrument used for acquiring brain signals. These signals are recorded and displayed within amplitude at around microvolt (μV) order to represent neurons activity beneath its skull area [Baars, B.and Cage,N,2010]. Examination by using this procedure has been used since 1920s by medical practitioners to provide neurologic and psychiatric diagnoses, including traumatic cases [Schomer and Silva, 2011[Tudor, M,et al,2005].

Despite this feasibility, conventional (scalp) EEG may bring a drawback for examination intended for more accurate diagnostic approach due to its low-voltage record and low spatial accuracy. To overcome this problem, intracranial EEG (iEEG) or electrocorticography (ECoG) has been applied to record brain signals with higher amplitude and more localized than conventional one. iEEG is a modified type in which its electrodes or probes are directly placed on the exposed brain surface rather on the scalp, hence it provide a better spatial resolution due to an impedance reduction [Kim, Y. J,et al,2015][Shenoy, P.,et al,2008]. These advantages have made it being applied not only for medical purposes but in plenty of researches as well [Shenoy, P.,et al,2008][McMullen, D. P.,et al,2014].

This study weighs out methods to differentiate any injury location from patients with TBI. One research shows that TBI case causes a lower spectral power in EEG compared to a healthier one [Napoli, A.,et al,2012], another research shows that there is alteration in spectral power in at least one frequency band [Rapp, P. E,et al,2010]. To decide this, EEG signals that have been recorded were analyzed with fast Fourier transform (FFT) to yield their absolute band power, and Welch's method to measure their power spectrum. Fourier analysis was chosen because it has been in used for power spectrum extraction in many EEG analyses, including TBI case [Mikola, A.,et al,2015]. Welch's method itself is a type of power estimator equipped with segmentation and overlapping process to yield a better accuracy measurement from stochastic signal like brain wave [Musson, J.and Li, J.,2002].We then compared the difference between signals analyzed by using FFT and by Welch's method to determine the injury locations.

METHODOLOGY

a.Patients Selection and Acquisition

A total of 5 records of brain signals from 5 patients were recorded throughout November 2015 until March 2016 (Table I). Patients came with same disease and gender with age range from 17 to 60 years old (mean 36.4), comprise of mild and moderate head injury based on their respective GCS.

Table I. Patient database

No.	Age (yr)	Gender	Electrode location	GCS[a]	Treatment delay (hr)
1	57	Male	Dura mater	14	11
2	60	Male	Dura mater	9	5
3	17	Male	Dura mater	12	19
4	20	Male	Dura mater	15	6
5	28	Male	Dura mater	13	15

Glasgow Coma Scale

The treatment delay is the hour between the occurred accident and patient's first administration in hospital. This might later play part in the concept that all neurological damage does not occur at the moment of the impact, but evolves over ensuing hours and days [Brain Trauma Foundation.,2002]. The same electrode location (dura mater) is important as different layer recordings might cause a power bias [Faried, A.,et al,2017]. All of these recordings were carried out in general anesthesia while they were being treated during surgical procedure for their respective diseases. The procedures were performed with patient's consent at Dr. Hasan Sadikin General Hospital, Bandung.

This study conducted by using a modified EEG instrument that had been tested to fulfill patient safety standard. This instrument is equipped with analog to digital converter (ADC) set with 250 sampling rate and 1x digital gain. The electrodes are sterilized 2x4 channels Pl-plated with Si-based probe, specialized for intraoperative usage. These electrodes, with total of 8 channels, were placed in a position where the craniotomy (skull-opening surgery) is located as described in fig 1. Channel 1-4 were put on the main injury foci by the doctors, meanwhile channel 5-8 were put on slightly less-damaged tissue. The acquisition process itself took 60 seconds for each patient thus one channel contains 15000 data. These signals then were recorded and saved into computer as .txt and .xls file.

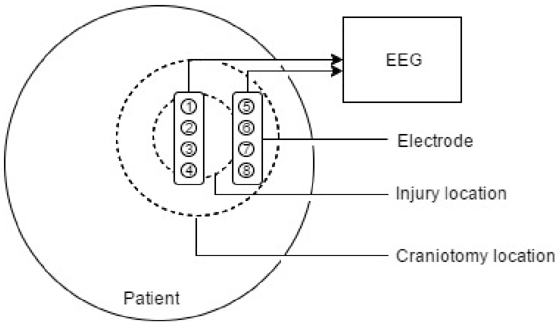


Fig. 1. Electrode placement

b.Signal Processing

Figure 2 explains the steps involved in the signal processing. By using MATLAB, these signals were extracted from .txt and .xls files mentioned earlier. First step starts with normalization process and then continued with the 50 Hz notch filter to remove the electrical wire noises. Next step is to apply a 40 Hz low pass filter to optimize noise removal and by this

step we may yield a standard EEG signal in time domain. These signal images are important because we can expertise it by comparing signals from channel 1-4 with channel 5-8 visually.
As we can see in figure 3, patient no. 1 and 5 have a distinct amplitude different between channel 1-4 and 5-8 thus made them easier to be concluded. However, patient no. 2, 3, and 4 have an amplitude difference that cannot be clearly seen (patient 4 signals might seem quite different, but its channel 3 actually has a bigger amplitude after 30th second compared with other channels). This must be analyzed later with power measurement explained below.

c. Power Spectrum Measurement

We use MATLAB application to measure signal power spectrum. The power spectrum explains the distribution of power present in the signal into frequency parts. Steps that mentioned earlier were continued by applying a band pass filter correlates with four bandwidths of EEG signal frequency (brain rhythm) [Sanei, S. and Chambers, J. A.,2007]:

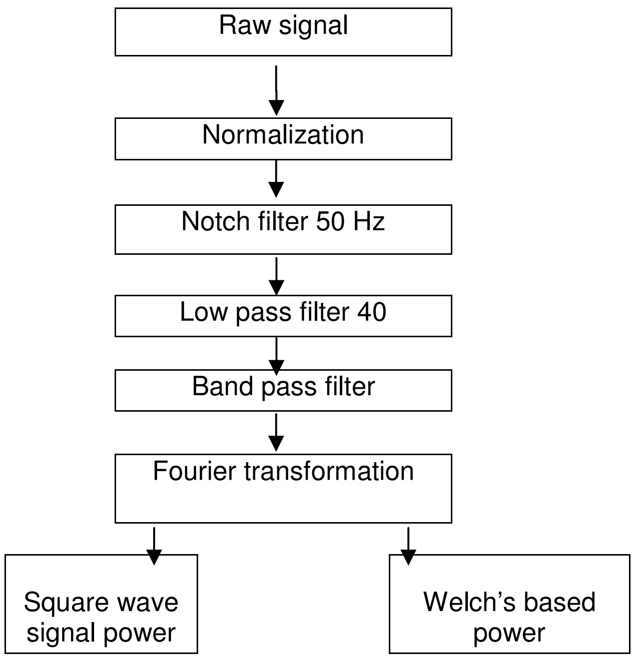
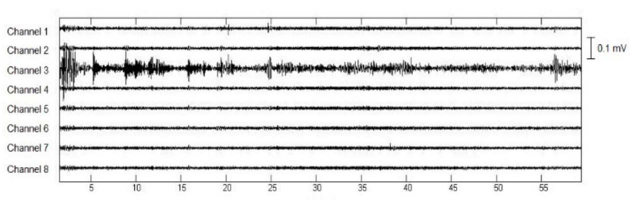
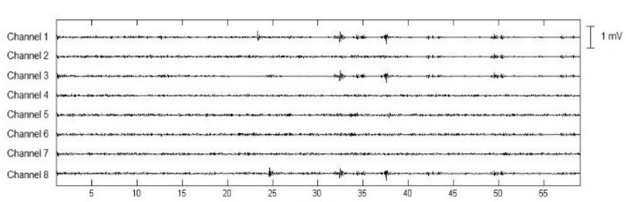


Fig2:Flow charts of the steps involved in signal processing

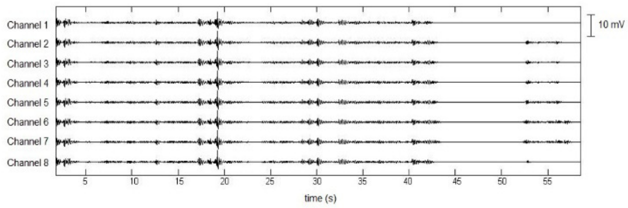
a) theta, θ (4-8 Hz)
b) alpha, α (8-13 Hz)
c) beta, β (13-30 Hz)
d) gamma, γ (30-45 Hz)



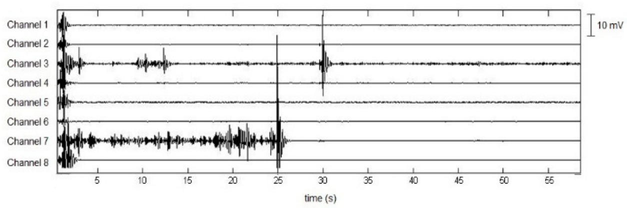
Patient no. 1



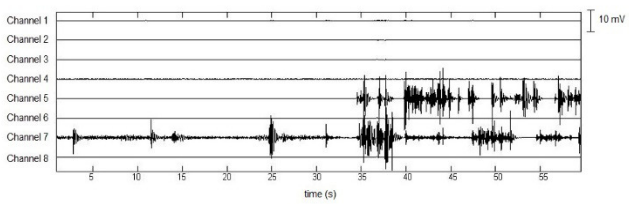
Patient no. 2



Patient no. 3



Patient no. 4



Patient no. 5

Fig3.Early filtering image of EEG signals from each patient

Then, we need a Fourier transform to obtain this spectrum from signal over time series with N length, then compute the average power for the entire squared input signal as described as follows:

$$Pf(x) = \frac{1}{N}\sum_{i=0}^{N-1}|f(x)|^2 \qquad (1)$$

We then compare it by using Welch’s method. It is a power estimator that also uses FFT, but differs in which it “windows” the data segments and allows it to overlap [Proakis, J. G.and Manolakis, D. G.,1996]. If L data segments with M length, overlapping by D points, then we can assume that if
D = M, the segments do not overlap. However if
D = M/2, there is 50% overlap between successive data segments. From this, the result is a modified periodogram

$$P_{xx}^{(i)}(f) = \frac{1}{MU}\left|\sum_{n=0}^{M-1} x_i(n)\,\omega(n)\,e^{-j2\pi f n}\right|^2 \qquad (2)$$

where U is a normalization factor for power analogous with (1)

$$U = \frac{1}{M}\sum_{n=0}^{M-1}\omega^2(n) \qquad (3)$$

Then the estimation of the power spectrum based on (2) is

$$P_{xx}^{W}(f) = \frac{1}{L}\sum_{i=0}^{L-1} P_{xx}^{(i)}(f) \qquad (4)$$

We use D = M/4 to estimate with four seconds of L data segments.

Because one patient has 2x4 channels, these data must be calculated into two average value representing each location. These power results then were put into two tables to find any differences among them.

RESULTS

Table II shows the average power of two groups by using FFT method. Channel 1-4 assumed as injury location and channel 5-8 as a slightly healthier one. Both channels were compared to measure their difference ratio, with ratio > 1 means that average power of channel 5-8 is higher than channel 1-4, thus confirming the hypothesis. The ratios then were categorized by their brain wave frequency bandwidth. We can see that four of five ratios are higher than 1 in all bands, with patient no. 5 has the highest ratio and patient no. 1 is the only one with ratio lower than 1. These results are analogous with table III, which shows the power by using FFT Welch's method. Four of five power ratios are higher than 1 in all bands.

Table II. Average power difference using fft

Patient No.	Channel	Average Power (μV^2)			
		Theta	**Alpha**	**Beta**	**Gamma**
1	1-4	0.336	0.129	0.118	0.022
	5-8	0.103	0.040	0.038	0.008
	Ratio	0.305	0.309	0.321	0.379
2	1-4	24.040	9.243	8.450	1.646
	5-8	26.811	10.261	9.417	1.837
	Ratio	1.115	1.110	1.114	1.116
3	1-4	1133.804	469.041	400.542	81.344
	5-8	1155.783	477.298	407.968	82.830
	Ratio	1.019	1.018	1.019	1.018
4	1-4	298.020	108.550	56.568	6.172
	5-8	867.618	234.407	147.433	23.814
	Ratio	2.911	2.159	2.606	3.858
5	1-4	0.788	0.320	0.311	0.063
	5-8	698.127	207.658	223.672	81.923
	Ratio	885.915	648.288	718.961	1296.537

Table III. Average Power Difference Using Welch's Method

Patient No.	Channel	Average Power (μV^2)			
		Theta	**Alpha**	**Beta**	**Gamma**
1	1-4	0.019	0.007	0.006	0.000
	5-8	0.003	0.001	0.001	0.000
	Ratio	0.187	0.117	0.109	0.257
2	1-4	0.718	0.133	0.064	0.009
	5-8	0.784	0.139	0.066	0.010
	Ratio	1.093	1.045	1.038	1.078
3	1-4	57.113	13.549	4.999	0.544
	5-8	58.189	13.690	5.087	0.555
	Ratio	1.019	1.010	1.018	1.021
4	1-4	86.438	26.224	13.058	1.333
	5-8	265.416	60.443	28.184	4.013
	Ratio	3.071	2.305	2.158	3.010
5	1-4	0.055	0.025	0.034	0.007
	5-8	276.095	78.529	87.817	27.277
	Ratio	5003.903	3108.592	2616.699	3885.090

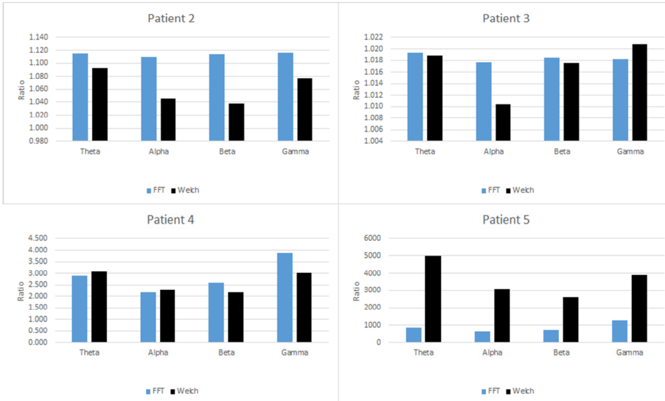


Fig 4. Comparison graphic of power difference between FFT and Welch

Next we compared the ratios of these four patients: Patient 2, 3, 4, and 5 (patient 1 is excluded) to determine if there is one method consistently outperform another. Figure 4 shows that in patient 2, FFT method has a higher ratio differences with valued at 1.115, 1.110, 1.114, and 1.116 compared with Welch's method at 1.093, 1.045, 1.038, and 1.078 from theta, alpha, beta, and gamma band respectively. By using two-tailed t-test, FFT method is significantly higher with p-value 0.03. However, patient 5 gives a different result, FFT method instead has a lower ratio at 885.915, 648.288, 718.961, and 1296.537 compared to Welch's method at 5003.903, 3108.592, 2616.699, and 3885.090. Welch's method is significantly higher than FFT with p-value 0.01. Meanwhile patient 3 and 4 have a mixed ratio difference.

DISCUSSIONS AND CONCLUSIONS

The results show both FFT and Welch method can be used to measure power spectrum of EEG signals from patients diagnosed with traumatic brain injury. A total of 80% patients with TBI exhibit a lower power of brain signal from their injured tissues compared with a slightly healthier parts. There is only one patient that exhibits a different result, this might be occurred from a recording error such as electrode misplacement or from patient condition itself.

While we can differentiate these powers from channels, there is no method that preferable compares with each other. Signals analyzed with FFT and Welch's have a different performance from four patients whose powers are related to above conclusion. FFT is more accurate for patient no. 1 and Welch's method is more accurate for patient no. 5, whereas patient no. 2 and 3 have a mixed responses.

In the future works, we will try to find any possibilities that may contribute to this conclusion, such as patient age [Fan, J. C.,et al,2014], GCS, or treatment delay. With more patients involved, this conclusion might be changed as well.

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REFERENCES

Baars, B.and Cage,N. (2010). Cognition, Brain, and Consciousness: Introduction to Cognitive Neuroscience. Elsevier.

Brain Trauma Foundation. (2002). Management and Prognosis of Severe Traumatic Brain Injury. American Association of Neurological Surgeons.

Fan, J. C., Cheung, R. T., Chu, L. W., Fung, P. C. W., Chang, C. Q., Sik, H. H., Zhang, M. M., Xie, B. J., Hung, Y. S. and Gao, J. L. (2014). Age-related changes of EEG and its source in resting state. 19th International Conference on Digital Signal Processing, 797 – 800.

Faried, A., Sabirin, M., Sutiono, A. B., Arifin, M. Z., Mengko, R. and Rajab, T. L. E. (2017). Comparison of Electroencephalography Power Spectral Density between Duramater and Brain Cortex. British Journal of Applied Sciences and Technology, 19(2), 1-6.

Kim, Y. J., Park, S. W., Yeom, H. G., Bang, M. S., Kim, J. S., Chung, C. K. and Kim, S. (2015). A study on a robot arm driven by three-dimensional trajectories predicted from non-invasive neural signals. BioMedical Engineering Online, 14(81). doi:10.1186/s12938-015-0075-8.

McMullen, D. P., Hotson, G., Katyal, K. D., Wester, B. A., Fifer, M. S., McGee, T. G., Harris, A., Johannes, M. S., Vogelstein, R. J.,

Ravitz, A. D., Anderson, W. S., Thakor, N. V.and Crone, N. E. (2014). Demonstration of a Semi-Autonomous Hybrid Brain–Machine Interface Using Human Intracranial EEG, Eye Tracking, and Computer Vision to Control a Robotic Upper Limb Prosthetic. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 22(4), 784 – 796.
Menon, D. K., Schwab, K., Wright, D. W., Maas, A. I. (2011). Position Statement: Definition of Traumatic Brain Injury. Archives of Physical Medicine and Rehabilitation, 91(11), 637-1640.
Mikola, A., Rätsep, I., Särkelä, M. and Lipping, T. (2015). Prediction of outcome in traumatic brain injury patients using long-term qEEG features. 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), 1532 – 1535. doi: 10.1109/EMBC.2015.7318663.
Musson, J.and Li, J. (2002). A Comparative Survey of PSD Estimation Methods for EEG Signal Analysis. IEEE Signal Processing Magazine Old Dominion University, Norfolk.
Napoli, A., Barbe, M., Darvish K. and Obeid, I. (2012). Assessing traumatic brain injuries using EEG power spectral analysis and instantaneous phase. Engineering in Medicine and Biology Society (EMBC), 4692-4695.
Proakis, J. G.and Manolakis, D. G. (1996). Digital Signal Processing. Principles, Algorithms, and Applications (3rd Ed). Prentice-Hall International.
Rapp, P. E., Keyser, D. O., Albano, A., Hernandez, R., Gibson, D. B., Zambon, R. A., Hairston, W. D., Hughes, J. D., Krystal, A.and Nichols, A. S. (2010). Traumatic Brain Injury Detection Using Electrophysiological Methods. Frontiers in Human Neuroscience. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4316720/
Sanei, S. and Chambers, J. A. (2007). EEG Signal Processing. John Wiley & Sons.
Schomer, D. L. and da Silva, F. L. (2011). Niedermeyer's Electroencephalography: Basic Principles, Clinical Applications, and Related Fields. (6th Ed). Lippincott Williams & Wilkins.
Shenoy, P., Miller, K. J., Ojemann, J. G. and Rao,R. P. N. (2008). Generalized features for electrocorticographic BCIs. IEEE Transactions on Biomedical Engineering. 55(1), 273–80.
Silver, J. M., McAllister, T. W., Yudofsky, S. C. (2005). Textbook of Traumatic Injury. American Psychiatric Publishing, Inc.
Tudor, M., Tudor, L. andTudor, K. (2005). The History of Electroencephalography, Acta Med Croatica, 59 (4), 307-13.