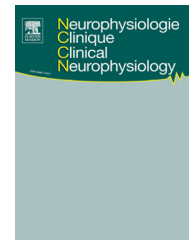Disponible en ligne sur

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ORIGINAL ARTICLE

Stroke identification using a portable EEG device — A pilot study

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Summary

Objective. — Changes in EEG patterns during stroke are almost immediate; however, a full EEG test takes time and requires highly qualified staff. In this study, we examined whether a short recording using a portable EEG device can differentiate between a stroke and control group.

Methods. — EEG samples were collected from patients with an acute ischemic stroke event. The control group comprised healthy volunteers. EEG recordings were recorded using a portable brain wave sensor device. The Revised Brain Symmetry Index (rsBSI) was used to quantify the symmetry of spectral power between the two hemispheres.

Results. — The investigation group included 33 patients (ages 46—96, mean age 72 years, 66% male) who were diagnosed with ischemic stroke. The control group included 25 healthy individuals. Scores for the rsBSI of non-stroke patients (M = 0.1686, SD = 0.10) differed significantly from those of ischemic stroke patients (P < 0.05, M = 0.363, SD = 0.25).

Conclusions. — A statistically significant difference was observed between a group of stroke patients and a matched group of healthy controls with a short recording using a portable EEG device.

Introduction

Time is crucial in stroke diagnosis. It affects mortality rates, rehabilitation, post-stroke quality of life, and medical costs in the short and long-term [1,2,6]. Although CT and MRI imaging both allow detailed assessments of brain anatomy

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and pathology and are valuable for measuring the cause (thrombosis or hemorrhage) and extent of a stroke, studies show that there is a time window of 6 to 8 hours before a stroke can be readily identified using CT. On the other hand, although MRI imaging is more accurate and can identify stroke within 30 minutes, it is less available and may take longer to perform even in a major medical center [2,4,5]. Furthermore, in many stroke patients, significant clinical presentation is absent or non-conclusive until later stages of the ischemic event. In such incidents, referral to medical centers and access to CT or MRI may be delayed in favor of other, seemingly more urgent cases.

Various studies [2,3] have shown that changes in EEG patterns during stroke are almost immediate. For example, as brain function deteriorates, high-frequency brain waves (such as gamma and beta waves) are attenuated and slow-frequency brain waves (such as alpha, theta and delta) become dominant [3]. In addition, stroke affects the symmetry of brain wave activity. As a patient's medical condition progresses from ischemia to infarction, changes in EEG patterns arise quickly. However, these changes may be observed only via quantitative EEG evaluations.

Van Putten's Revised Brain Symmetry Index (rsBSI) is a quantitative EEG parameter that uses Fourier series to detect asymmetries in spectral power between the two cerebral hemispheres. The rsBSI parameter should therefore allow early recognition of a stroke [9,10]. However, thus far, the rsBSI has mainly been employed for prognosis and follow-up, using EEG samples gathered over long periods of up to 24 hours. For instance, Stojanovic and Djurasic or Xiyan and colleagues showed the rsBSI to be a valuable tool in predicting and following up stroke patients' recovery and rehabilitation [7,11,12]. Xiyan and colleagues also used the rsBSI in conjunction with other clinical indicators to tailor the medical management and treatment offered to stroke patients [11].

In summary, although EEG lacks the detailed high-resolution information provided by CT or MRI, it is an inexpensive and sensitive tool that can be used to evaluate brain function, cerebral blood flow, and the clinical status of stroke patients. However, performing a full EEG test takes time and requires highly qualified staff, which tends to render the traditional test less relevant for early stroke recognition. When ''time equals brain'', the earlier a diagnosis (or suspected diagnosis) is made, the better the treatment a patient can be offered, and the better the prognosis. In this study, we examined whether a short recording using a portable EEG device can differentiate between a stroke and control group, employing the rsBSI parameter.

We hypothesized that, when an ischemic event unfolds, the changes in electrical brain activity would be rapidly identifiable by the portable EEG device. By relying on Fourier series as the basis for the mathematical analysis, we speculated that even small changes in brain activity would be perceived and thus that small-scale ischemic strokes could be diagnosed.

Our study looked for an association between the rsBSI parameter and the presence and degree of an ischemic stroke. This connection, if present, would allow an early and more accurate detection of such events using simple and practicable tools.

Methods

Study population

The study population comprised patients referred to the neurology ward at the Bnai—Zion medical center, a medium-sized hospital in the north of Israel from January 2016 to December 2018; with an ischemic stroke event verified clinically with the aid of CT or MRI scans. Patients with underlying neurologic conditions such as degenerative or demyelinating diseases or epilepsy, and those receiving anti-epileptic drugs, were excluded. EEG samples were collected no later than 48 hours from the onset of the stroke. The control group comprised healthy volunteers with no history of stroke events or underlying neurologic diseases.

The study was conducted according to the revised Declaration of Helsinki and was approved by the Ethics Committee of Bnai Zion hospital. All patients included in the study were able and willing to give informed consent.

Clinical assessment

Baseline examination of patients included a full medical history, physical examination, routine blood biochemistry and blood count, and brain CT or MRI scans. The onset of stroke was defined as the last verified time the patient was known to be without neurological deficits or symptoms. In addition, neurological function was quantitively assessed on the day of admission using the National Institutes of Health Stroke Scale (NIHSS). All patients were treated according to standard practice guidelines.

EEG acquisition

During recording the patients were awake, alert and in a sitting position. EEG recordings were sampled and recorded for at least ten minutes using the portable MUSE® brain wave sensor device by Interaxon Inc. (Toronto, Ontario, Canada). The device uses four recording electrodes (AF7, AF8, TP9, TP10) and one reference electrode (Fpz) according to the international 10—20 system. The data were transmitted via Bluetooth 2.1 and EDR using the MCP protocol and recorded using the MUSE Lab and MUSE player programs. The recording frequency of the MUSE device was set to a value of 220 Hz. The Hamming window was set to 256 samples.

The Fast Fourier Transform (FFT) computes the power spectral density of each frequency on each channel. Regarding these FFTs, the MUSE device allows calculation of values in a range of 0—110 Hz for each channel. This range is divided into 129 bins, one for each of the 256 sample window slots divided by 2 (due to reflected symmetrical values) and an additional slot for 0 Hz. Thus, every index of the FFTs represents an incremental 0.86 Hz (starting at 0 Hz) up to a total of $128 \times 0.86\,Hz = 110\,Hz$.

With a Hamming window of 256 samples (at 220 Hz recording rate) and a slide window of 22 samples over (1/10th of a second) we allowed a 90% overlap from one window to the next. This data is transmitted by the MUSE device at 10 Hz to be used by the rsBSI calculation algorithm suggested by Van Putten [10].

The Revised Brain Symmetry Index (rsBSI) was introduced as an improved version of the Brain Symmetry Index for continuous quantitative EEG monitoring in hemispheric stroke patients [10]. The algorithm employed in the research uses the rsBSI parameter to quantify the symmetry of spectral power (power spectrum density, or PSD) between the two hemispheres.

Data analysis

For the present study, 10-minute epochs of EEG recording were recorded and analyzed. All routines and algorithms were implemented in MatLab (Mathworks, Natick, Massachusetts, USA).

By their nature, noise and artifacts increase the level of asymmetry present in the gathered data. In addition, incomplete discrete points of recording increase the calculated rsBSI values. Therefore, to achieve maximal accuracy and reliability, special care was taken to reduce noise and to ensure that artifacts were cleaned and removed from each sample before data were used to calculate the rsBSI values.

The MUSE device uses a Driven Right Leg Circuit (DRL) to actively reduce noise originating from common mode interferences. This notch filter was set to 50 Hz in compliance with the European standard. The MUSE device has also 3 signal quality indicators. All of these 3 indicators were set to the highest level with samples not fitting removed. The next stage was data filtering with settings of 0.16—76 Hz. After this stage, the data was ready to be processed and analyzed.

In the first stage of analysis, the length of each sample was reviewed. Only samples longer than five minutes after the noise reduction were included in the second stage of analysis — calculating the rsBSI for different frequency ranges and identifying patterns that characterize each of the sample groups (stroke patients and controls).

Isolated points of non-continuous information flow were also excluded even if data were incomplete in only one channel.

Statistical analysis was performed using Microsoft Excel and Statistical Package for the Social Sciences (SPSS). All data were analyzed offline.

Results

The investigation group included 33 patients (age 46—96, mean age 72 years, 66% male) who were diagnosed with ischemic stroke. Overall NIHSS range was 0—16, including 0 (no symptoms) for 1 patient; 1—4 (minor symptoms) for 22 patients; 5—15 (moderate symptoms) for 9 patients; and 16 (moderate to severe symptoms) for 1 patient. The control group included 25 healthy volunteers (age 43—80, mean age 60 years, 52% male).

In nine patients, a follow-up EEG test performed after 2—3 months was also available.

Scores for the rsBSI of non-stroke control group (M = 0.1686, SD = 0.10) (Table 1) differed significantly from those of ischemic stroke patients (M = 0.363, SD = 0.25) (Fig. 1).

Table 1 Median rsBSI scores of stroke patients acute and follow up EEG test vs. control group.

	Acute stroke (N = 33)	Stroke follow-up (N = 9)	Control group (N = 29)	P
RsBSI Median	0.363	0.213	0.169	P = 0.002
Ischemic Stroke	94.3%	—	—	
NIHSS Median	4.00	—	—	

Median values of rsBSI values distribution between different groups of study. Note that after the noise cleaning algorithm was applied, the difference of rsBSI mean values between the healthy and stroke groups became more apparent and significant, allowing better distinction between these two groups.
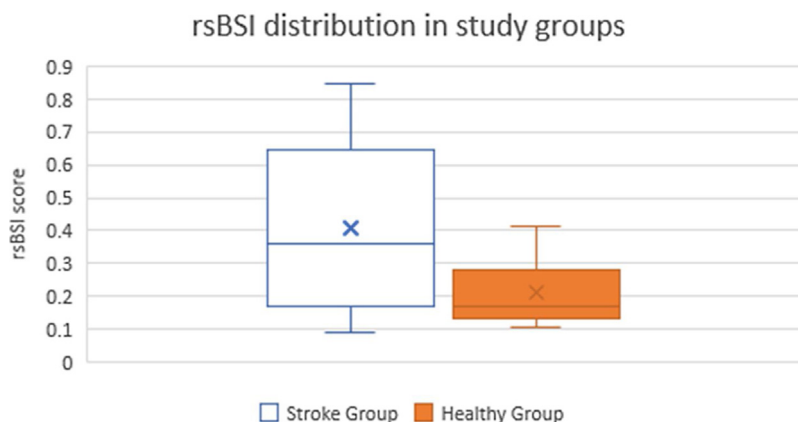

Figure 1 rsBSI distribution in the stroke group and the healthy control group. There is a considerable difference in the range and values of the rsBSI parameter with many of the stroke group patients demonstrating values far greater than the average, mean and upper limit values of the healthy group.

Patient number	Acute stroke rsBSI score	Follow up rsBSI score
1	0.6615	0.0848
2	0.8286	0.2352
3	0.2016	0.1708
4	0.5995	0.072
5	0.495	0.2427
6	0.2704	0.0656
7	0.1958	0.169
8	0.3993	0.1819
9	0.3787	0.2317
Median	0.375	0.213
P	P = 0.002	

There was a significant (U = 84.50, Z = − 1.878, p < 0.05, η = 0.10) effect of group on the NIHSS scores. The median NIHSS score of patients diagnosed through imaging was higher (4.00) than that of patients diagnosed only clinically (2.00). The mean ranks of patients diagnosed through imaging and those diagnosed clinically were 20.22 and 13.97, respectively.

The median rsBSI values of the nine stroke patients immediately after the stroke were 0.375. The median rsBSI values in the second recording carried out a few months after the stroke were 0.213 (P = 0.002) (Table 2).

Discussion

In our study, we acquired EEG samples from newly diagnosed stroke patients and processed their electrical brain function using the rsBSI. We found a statistically significant difference between the rsBSI values of the stroke patients and those of the healthy subjects. The stroke patients displayed higher rsBSI values, which correlate with the presence of ischemia, while the healthy subjects displayed lower rsBSI values, which correlate with a healthy, normally functioning brain.

Several signal processing methods can be used to assess the electrical activity of brain cells, including power spectral density, period and amplitude analysis, normalized slope description, and zero-line crossing variance. Tolonen and Sulg [8] showed that power spectral density was superior to the alternatives. Van Putten's revised Brain Symmetry Index [9,10] utilizes the power spectral density of brain wave signals (using Fast Fourier Transformation) to evaluate brain function and tissue damage. The rsBSI parameter captures patterns of asymmetry in electrical brain function between the right and left hemispheres [9,10]. The symmetry/asymmetry patterns are quantified as a single value used to assess the level of such discrepancies from baseline status. Van Putten and others [3,9,10,12] showed the rsBSI to be highly correlated with damage to brain tissue as a result of impaired blood flow in acute stroke patients.

To the best of our knowledge, our study is the first to utilize a portable EEG device in an attempt to sample and analyze EEG brain waves for medical purposes. Past studies [7,9—12] used full 10—20 system (16—32 channels) EEG. While traditional EEG allows reliable and relatively noise-free recording, this method is not practical for use outside the setting of a well-equipped hospital with well-trained staff. However, our data obtained from a low-cost, portable EEG device with four recording electrodes show the same trends as those reported by studies using the full 10—20 system EEG. These findings prove that a portable EEG device can be used to evaluate differences in rsBSI values and to detect the presence of ischemia.

In addition, in our study the EEG test duration was very short (approximately 10 minutes), as opposed to the prolonged tests conducted in previous studies. In his studies, Van Putten used continuous EEG monitoring for a period of 12 to 24 hours [9,10]. Similarly, Xiyan and colleagues used 12—24 hours of continuous EEG recording in one study [11] and a full 24 hours of continuous EEG recording in another [12]. Stojanovic and Djurasic [7] sampled short EEG sequences (20 minutes), but used a stationary EEG device with a full set of 32 electrodes. In contrast, the short recording time required by our method combined with the use of a portable EEG device enables testing for stroke during the initial evaluation, very soon after the patient's arrival in the emergency room.

In our study, a sub-group of nine patients was re-evaluated a few months after the onset of the stroke event, and rsBSI scores recorded. Each of the patients in the follow-up group showed a decrease in the second rsBSI value compared to the initial sample. The follow-up rsBSI values matched those of the healthy subjects and were statistically different from the (initial) rsBSI values of the stroke patients.

Another important finding in our study was that patients' rsBSI values correlated with their NIHSS scores. This supports the claim that asymmetry in electrical brain activity increases when impairment to blood flow is present and brain functions deteriorate. Our findings are in line with those of Van Putten or Xiyan and colleagues, who reported high correlations between rsBSI and NIHSS scores [9,11,12]. Our findings are also in line with the Barthel Index (BI) and modified Rankin Scale (mRS), which are used to measure post-stroke patient function [12].

Indeed, one major benefit of using EEG as a diagnostic tool is that changes in EEG wave patterns become manifest within seconds after the onset of the stroke [2,4]. This fact, combined with the high sensitivity of EEG in detecting even minor brain function deviations, means that EEG with rsBSI may be used to identify small stroke events that might otherwise go undiagnosed and untreated.

Limitations

While our study showed a statistically significant difference between a group of stroke patients and group of healthy controls, the groups were not matched. In the present study, we were not able to identify an rsBSI score which was pathognomonic for stroke in a specific patient. We hope to achieve this goal in future research using better quality electrodes and with an expanded study population.

Conclusion

In this pilot study, we showed a statistically significant increase in the asymmetry of brain wave electrical signals

between the stroke group compared to healthy controls, using a portable EEG device. Further research is needed in order to investigate the clinical implication for a quick, simple and reliable tool in the diagnosis of ischemic stroke.

Funding

Disclosure of interest

The authors declare that they have no competing interest.

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