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Correlation Between Poststroke Balance Function and Brain Symmetry Index in Sitting and Standing Postures

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Abstract— **Balance problems are the main sequelae of stroke, which increases the risk of falling. The assessment of balance ability can guide doctors to formulate rehabilitation plans, thereby reducing the risk of falls. Studies have reported the role of resting-state EEG during sitting in the motor assessment of the upper extremity and prognosis of stroke patients. However, the above research in the sitting posture lacks specificity in evaluating the balance ability of the lower limbs. Herein, this article investigated whether EEG was different in sitting and standing positions with different difficulty levels and validated the feasibility of EEG in assessing body balance ability. The resting-state EEG signals were collected from 11 stroke patients. The pairwise-derived brain symmetry index (pdBSI) was used to identify the differences in EEG-quantified interhemispheric cortical power asymmetry observable in healthy versus cortical and subcortical stroke patients by calculating the absolute value of the difference in power at each pair of electrodes. Subsequently, we computed the pdBSI over different frequency bands. Balance function was assessed using the BBS (Berg Balance Scale). Stroke survivors showed higher pdBSI (1-25 Hz) values in standing posture compared to sitting (p <0.05) and the pdBSI was significantly negatively correlated with BBS (r = −0.671, p =0.034). Additionally, the pdBSI within beta band was also significantly negatively correlated with BBS (r = −0.711, p=0.017). In conclusion, stroke brain asymmetry in standing posture was significantly more severe and the pdBSIs in 1-25Hz and beta hand were related to balance function. BBS and NIHSS was significantly negatively correlated (r = −0.701, p = 0.024), and NIHSS was significantly correlated with age (r = 0.822, p = 0.004). The present study suggests that stroke can seriously affect the body's balance ability. Compared with the sitting posture, the asymmetry of cortical energy in the standing posture can better assess the patient's balance ability.**

Keywords— **Stroke; pdBSI; Balance function; Sitting and standing postures**

I. Introduction

The balance function is especially important for maintaining various postures, performing kinds of activities, and producing appropriate responses to external interference in daily life. Most of stroke survivors who suffer from lower limb paresis and limb incoordination, which seriously affects balance[1]. Balance dysfunction often affects the overall motor function, which greatly increases the probability of fall injuries. The balance function assessment can help physicians identify the patients' remaining motor abilities and functional deficits. Then physicians formulate rehabilitation plans according to the assessment to improve the patients' balance ability. Therefore, rehabilitation assessment of balance ability is an important part of rehabilitation treatment and an effective method to prevent patients from falling. At present, in clinical practice, the Berg Balance Scale (BBS) is often used to evaluate the balance function of patients with cerebrovascular and brain injury[2]. It evaluates the ability of the patient's active center of gravity transfer by observing a variety of functional activities, and also carries out a comprehensive examination of the patient's dynamic and static balance under the sitting and standing positions. BBS has been widely used in clinical practice, showing good reliability, validity and sensitivity. However, the scale is evaluated by the external physical signs of patients, which has the defects of semi-quantitative and strong subjectivity. Besides, the BBS is an indirect measure of neural deficits, and its relationship with direct biomarkers of cortical state are still underexplored[3].

Electroencephalography (EEG), recording changes in cerebral cortex potential, has been used as a tool for monitoring and diagnosing prognosis during the operation[4, 5]. Knowledge about the association between clinical neurological impairment and cortical activity can be of value to provide more insight into the cortical reorganization accompanied with stroke recovery. Quantitative EEG (qEEG) extracts features from recorded raw EEG signals and thereby help clinicians understand the clinical status of each patient. The brain symmetry index (BSI) was one of the most widely used qEEG parameters[6]. BSI reflects the amount of asymmetry in spectral power of the EEG signal between homologous channels forming pairs over the affected and unaffected hemisphere. Studies have shown that scores for the BSI of non-stroke control group differed significantly from ischemic stroke patients in sitting postures[7]. The BSI value of stroke patients is larger, indicating that the injury has caused obvious asymmetry in the left and right hemispheres. We also know that in the clinic, most stroke patients show hemiplegia, that is, unilateral body movement dysfunction. Therefore, BSI is consistent with clinical characteristics.

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Static balance, one of the balance types, is called first-level balance, which refers to the process of maintaining a certain posture stability when the body is open and closed without external force, such as sitting balance and standing balance. It was shown that in the continuous steady-state balance control task, as the difficulty of the task increased, the difference in electrode energy between the left and right hemispheres became more obvious[8].Therefore, we hypothesized that the brain asymmetry evoked by more difficult postural tasks can better reflect the patient's dysfunction. This study collected EEG signals of patients in two different postures of static balance.Then we investigated whether pdBSI was different in the two postures and validated the feasibility of pdBSI in assessing patient's body balance ability.

II. Materials And Methods

A. Participantss

The present study recruited 11 patients with first-ever stroke (7 females and 4 males, 53.8 ± 13.8 years) from the stroke rehabilitation unit at Tianjin Medical University General Hospital. The data collection was undertaken averagely 111 days post-stroke onset. Inclusion criteria were: (i)first stroke according to MRI, (ii)standing for 5 minutes without support, (iii)no cognitive deficit. The scales used for the lower extremity balance assessment was Berg Balance Scale (BBS) and the neurological deficits was National Institute of Health Stroke Scale (NIHSS). Table I provides a summary of demographic information sorted by the severity of the stroke. Ethics approval was obtained from the Tianjin Medical University General Hospital in China.

TABLE I. CLINICAL CHARACTERISTICS AND SITUATIONS OF STROKE PATIENTS

Patients	Infarct site	Gender	Age	NIHSS	BBS
1	Right	M	57	1	52
2	Right	F	64	2	41
3	Left	F	51	2	51
4	Right	F	74	5	33
5	Left	M	49	3	40
6	Right	M	67	-	-
7	Left	M	60	4	55
8	Left	F	33	1	46
9	Left	F	38	0	56
10	Left	F	32	0	55
11	Right	F	67	4	40

B. EEG Recording

The EEG signals were collected using the Neuroscan Greal EEG system (Australia). Signals were recorded using 16 electrodes placed on the scalp at standardized positions F7, F3, FZ, F4, F8, C3, CZ, C4, P3, Pz, P4, O1, OZ, O2, M1 and M2 according to the International Standard System 10-20. The vertex electrode was used as reference with all electrode impedances less than 15 kΩ. The sampling frequency was set to 1024 Hz. EEG was recorded during siting in a comfortable chair and standing at least 5 min with eyes opened. During recording, participants were asked to avoid unnecessary movements and keep their eyes open, aside from normal blinking. The EEG signals were collected in a quiet room of hospital.

C. EEG processing

Preprocessing. In order to increase the SNR and obtain more accurate EEG information, the EEG data was preprocessed before characteristic calculation. The original EEG signals were referenced to the mastoid. Then, the signals were filtered by an impulse response band-pass filter with cut-off frequencies of 0.5-30Hz, then down sampled to 512Hz. Afterwards, the independent component analysis (ICA) was performed to remove the blinking and other artifacts. The whole process of EEG signals was performed using the well-known Matlab R2018a (MathWorks, MA, USA), with the toolbox EEGLAB[9].

Pairwise derived Brain Symmetry Index. We separately processed 4 minutes resting-state EEG in two different postures for each patient. The EEG signals were divided into 30 subsequent epochs of 8s. We believed that the EEG signals were stable during this period. Power spectral density (PSD) was calculated using Pwelch, modified periodogram spectral estimation method with 50% overlap. In order to calculate the energy difference between the two hemispheres, the electrodes in the left and right hemispheres were divided into two regions according to Fig.1.

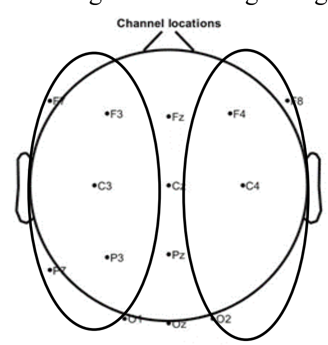

Fig.1. The figure shows the grouping of the electrodes in the two regions (right and left)

The pdBSI evaluates global asymmetry along homologous channel pairs over the different frequency bands 1-25 Hz, delta (1-4Hz), theta (4-8Hz), alpha (8-12Hz) and beta (12-30Hz). It can be calculated as follows:

$$\text{pdBSI} = \frac{1}{MN}\sum_{j=1}^{M}\sum_{i=1}^{N}|\frac{R_{ij}-L_{ij}}{R_{ij}+L_{ij}}| \qquad (1)$$

where R_{ij} and L_{ij} being the FFT based power spectral density using Pwelch's method of the signal obtained from a right and left channel of a homologous channel pair (with j = 1,2,...,M) at frequency j (with index i = 1, 2,..., N) respectively.

D. Statistical Analysis

The statistical analysis was performed using MATLAB R2018a. In this study, we firstly analyzed the differences of pdBSI and the topographic map of energy distribution under the two postures in the 1-25Hz frequency band. Then, the correlation between pdBSI and BBS was investigated.

The differences of qdBSI in sitting and standing postures were investigated using Wilcoxom Signed Rank Test. According to the size of patients, normality of data was tested using the Shapiro–Wilk test. Selection of correlation method between BBS and pdBSI according to the results obtained by the Shapiro–Wilk test. When the normality could be assumed, the correlation was made using Pearson's linear correlation test; otherwise, the correlation was done using Spearman's rank correlation test. The statistical significance level was set at $p < 0.05$. Asterisks in Fig.2 indicate which comparative analysis testing achieved this statistical significance level of $p < 0.05$.

III. Result

A. The differences of pdBSI

Results of pdBSI in the 1-25Hz obtained from EEG data recorded at sitting and standing postures of each patient were shown in Fig.2, respectively. The pdBSI values of 11 patients in two different postures were calculated and the overall mean values that were presented as mean ± standard error: 0.157±0.052,0.191±0.075. Wilcoxom Signed Rank Test showed that a statistically significant difference was observed between the pdBSI obtained from sitting and standing postures (p =0.032, $p < 0.05$). The pdBSI was noted to be higher in standing postures compared to sitting, which indicated higher asymmetry in brain activity in the case of standing posture. This obvious asymmetry also indicated that there was a stronger difference in the degree of activation of the left and right hemispheres when the patient maintained the body's standing balance. This represented the focal disruption that arises in one hemisphere following stroke.

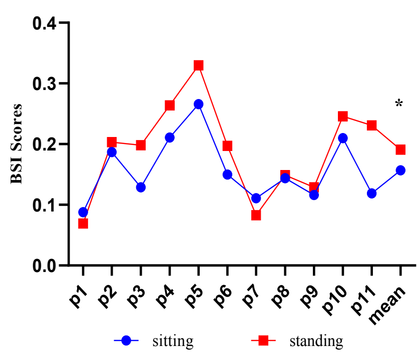

Fig.2. The differences of BSI between sitting and standing postures of each patient. Red dots indicated the the value of BSI in standing posture. Blue dots indicated the value of BSI in sitting posture.

In order to analyze the cortical energy distribution of the patient in two different postures, the PSD of EEG data within 1-25Hz were calculated. We used the symmetrical method of EEG electrodes to unify the patient's affected side to the left. Then the average energy of each electrode was calculated by averaging the corresponding electrodes. Fig.3 showed the distribution of the average energy of all patients in two different postures. It can be seen that the differences in energy distribution between the left (affected) and right (unaffected) hemispheres was more obvious in standing posture. Moreover, the unaffected side had a greater degree of activation than the affected side for both sitting and standing postures.

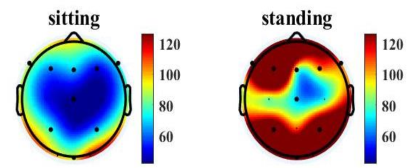

Fig. 3. Topoplot of the PSD evaluated from patient during the sitting and standing postures.

B. Correlations Between pdBSI and balance function

Associations were tested for clinical characteristics: age, and neurological deficits. During the scale evaluation process after the EEG test was completed, a patient failed to complete the corresponding scale evaluation due to physical problems. Therefore, we analyzed the correlations between pdBSI and BBS in 10 patients. Normality of all data was tested using SPSS Version 13.0 software for Windows. Wilcoxom Signed Rank test showed that clinical characteristics were not in gaussian distribution. Therefore, the correlation was done using Spearman's rank correlation test.

The associations between pdBSI and BBS scale were shown in Fig.4. No significant association was found between the pdBSI of sitting posture with BBS ($r = -0.592$, p =0.072). However, significant negative association with BBS was confirmed for the pdBSI of standing posture ($r = -0.671$, p=0.034). Experimental results showed that the brain symmetry index in the standing posture was significantly negatively correlated with the assessment of the balance ability of stroke patients. Specifically, the greater the pdBSI value, the poorer the patient's balance ability. Conversely, the smaller the BSI value, the better the patient's balance ability. Moreover, the pdBSI of resting EEG have no significant correlation with age (p>0.05).

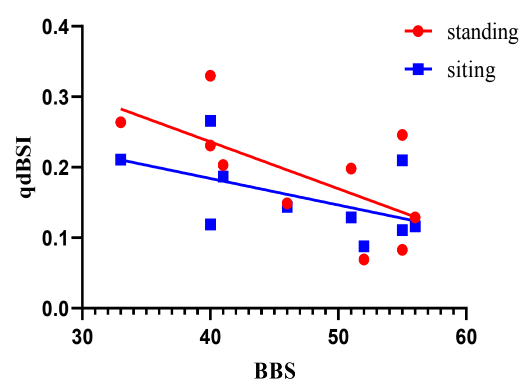

Fig.4. The associations between pdBSI and BBS scale. Blue dots indicated the value of BSI in sitting posture.

Further, the pdBSI in standing posture over delta 4Hz), theta, alpha and beta frequency bands were also obtained. The correlations between the pdBSI in standing of the four frequency bands and BBS were analyzed. The results showed that the BBS had a significant correlation with the pdBSI only in the β band ($r = -0.711$, $p = 0.017$).

C. Associations among clinical characteristics

We also analyzed the correlation between clinical measures. The analysis results showed that BBS and NIHSS are significantly negatively correlated ($r = -0.701$, $p = 0.024$), and NIHSS is significantly correlated with age ($r = 0.822$, $p = 0.004$). Specially, in the balance ability assessment of stroke patients, the more severe the patients were, the worse their balance ability would be. The results showed that after a period of rehabilitation training, the patient's balance ability was related to the severity of the current stroke.

IV. Conclusion and Discussion

We studied the differences of pdBSI of stroke patients in two different difficult postures, and the feasibility of pdBSI as a biomarker to assess lower extremity balance function post stroke. Significant differences between sitting and standing postures were found in pdBSI. The asymmetry of the brain was more obvious when the patients were standing. There was a negative correlation between the pdBSI value of the standing posture and the body balance ability detected by the BBS scale (pdBSI of 1-25Hz & BBS: p=0.034, pdBSI of beta band & BBS: p=0.017).

Our results support the hypothesis that stroke survivors in standing posture have a higher pdBSI compared to sitting posture. While existing literatures particularly focused on the acute and subacute phase[10, 11], our study showed that this asymmetry may persist after the acute phase of stroke. The association between pdBSI in standing and BBS implies that brain asymmetry may be a useful biomarker for the balance state after stroke and may provide more insight in the relation between reorganization of the cortex and motor recovery. In addition, our result suggests that parameters based on power spectral densities are of value in understanding impaired motor function in chronic stroke.

Acknowledgment

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