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Correlation of Body Composition via Bioelectrical Impedance Analysis and Motor Function and Recovery of Upper Extremity in Patients Undergoing Stroke Rehabilitation

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HIGHLIGHTS

- The Δ Phase angle showed significant linear inverse correlation with motor function of upper extremity (UE).
- Bioelectrical impedance analysis has the potential of additional index for predicting the motor function of UE in early stroke rehabilitation unit.

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ABSTRACT

Bioelectrical impedance analysis (BIA) has been used to investigate the body compositions and predict functional outcomes in patients with stroke, while the role of BIA to predict motor function or recovery in stroke has not been clarified. This study aimed to investigate relationship between body composition measured by BIA and upper limb motor function and recovery. Body compositions (soft tissue lean mass, phase angle, body fat mass and body water) of fifty patients who are admitted to the stroke rehabilitation unit were segmentally analyzed via BIA. The motor recovery of upper extremity (UE) was evaluated via Fugl-Meyer Assessment (UE-FMA) at the time of transfer and discharge. Correlations between body composition and UE-FMA at discharge were analyzed using Spearman correlation coefficient. Multiple regression analysis was used to determine the regression between body composition and motor function and recovery. The Δ Phase angle, the difference of both sides was significantly linearly inversely correlated with UE-FMA at discharge. However, in multiple regression analysis, body compositions including phase angle did not significantly predict motor function at discharge or motor recovery. The Δ Phase angle is related to the severity of upper limb motor function at discharge in subacute stroke patients, and further studies are needed to determine its value as a predictor for motor recovery.

Keywords: Stroke; Rehabilitation; Body Composition; Motor Skills; Upper Extremity

INTRODUCTION

Stroke is the second leading cause of death worldwide [1]. Many patients suffer from the prolonged physical dysfunction after hospital discharge, and the recovery of motor function is crucial for the patients to regain independence. Hemiplegic stroke leads to various muscle abnormalities including denervation, disuse, inflammation, remodeling and spasticity underlying changes in muscle tissue phenotype and atrophy [2]. Evaluating muscle changes and function on the hemiplegic side in patients with subacute hemiplegic stroke is important for predicting the degree of functional disability.

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Conflict of Interest

The corresponding author of this manuscript is an editor of *Brain & NeuroRehabilitation*. The corresponding author did not engage in any part of the review and decision-making process for this manuscript. The other authors have no potential conflicts of interest to disclose.

Several methods are used to assess skeletal muscle mass or other body composition after stroke, including computed tomography (CT), ultrasound, bioelectrical impedance analysis (BIA), dual-energy X-ray absorptiometry, biomarkers, and anthropometry [3]. BIA is commonly used to evaluate total body composition in clinical and community settings due to the simple and non-invasive method involved. Several studies have recently reported the utility of BIA after stroke to predict clinical outcomes. Nagano et al. [4] investigated whether the gain in muscle mass may be positively associated with functional recovery in patients with sarcopenia after stroke. Kim et al. [5] investigated the body composition of affected and unaffected limbs after hemiplegic stroke.

Nutritional supply and status during rehabilitation are important factors for the prevention of muscle loss and to promote functional recovery in patients diagnosed with stroke. In addition, poor nutritional status on admission is predictive of long-term functional outcome in stroke patients [6]. The geriatric nutritional risk index (GNRI) has been used as an objective indicator of nutritional status based on serum albumin levels and body mass index (BMI). In BIA, phase angle has been regarded as an indicator of membrane integrity and water distribution between intra- and extracellular spaces [7]. Because phase angle has been used to predict body cell mass, it has also been used as a nutritional indicator in adults and children [8,9]. Recent studies have reported that phase angle of the whole body measured by BIA at the onset of stroke was independently associated with functional independence measure motor score at discharge [10,11]. Until now, various variables such as age, sex, lesion site, initial motor impairment, motor-evoked potentials and somatosensory-evoked potentials have been considered as predictors of upper limb motor recovery. The systematic review of literature suggested that the most significant predictor is the initial severity of motor impairment or function [12]. However, BIA can be used as a screening tool in the early stage of stroke in patients who cannot accurately measure motor function due to lack of cooperation. Although there have been studies on the correlation between body component and upper limb function [13,14], the regression between body component and upper limb motor function at discharge and motor recovery in stroke patient is still unknown.

Given the need for an objective method to predict upper limb motor function and recovery, the present study aimed to determine the prognostic value of BIA recorded from subacute stroke patients in predicting upper limb motor function at discharge and motor recovery.

MATERIALS AND METHODS

Participants

Patients with stroke who were transferred to the inpatient neurorehabilitation unit after treatment for the subacute phase in a tertiary hospital from January 2019 to December 2020 were selected for the study.

The inclusion criteria were: 1) stroke detected via CT or magnetic resonance imaging (MRI), 2) hemiparesis after stroke, 3) no previous ischemic or hemorrhagic stroke, 4) a Mini-Mental State Exam (MMSE) score ≥ 10, 5) subacute (within 50 days) stage, and 6) rehabilitation treatment for about 4 weeks. The exclusion criteria were: 1) any musculoskeletal disorder or neurological disorders causing weakness or muscle atrophy, 2) severe edema of upper limb, 3) severe medical conditions, 4) MMSE score < 10, and 5) severe apraxia or attention deficit.

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This study was conducted in accordance with the Declaration of Helsinki. The use of patient data for research purposes was approved by the research Ethics Committee at the Incheon St. Mary's Hospital, Catholic University of Korea (Approval No. OC21RASI0083).

Measurements

The study design was a retrospective study based on a review of medical records. Data collected included the age at stroke onset, sex, type of stroke, hemiplegic side, Days from onset (the period between the stroke onset and the BIA measurement date), Charlson Comorbidity Index (CCI) [15], initial National Institutes of Health Stroke Scale (NIHSS) score, Modified Barthel Index (MBI) for functional status of patients, and MMSE for cognitive assessment. NIHSS was measured at the onset of stroke, and MBI, and MMSE were measured within 3 days of transfer to the stroke rehabilitation unit. To evaluate initial nutritional status, we assessed the GNRI on transfer to the stroke rehabilitation unit, which was calculated as follows [16]:

$$1.489 \times \text{Serum Albumin (g/L)} + 41.7 \times \text{Weight at Transfer (kg)}/\text{Ideal Body Weight (kg)}$$

BMI (kg/m^2) was calculated from the patients' height and weight at the time of BIA.

Motor function assessment

To analyze the motor function of hemiplegic side of upper extremity (UE), Fugl-Meyer Assessment of UE (UE-FMA) involving affected side was also evaluated at the time of transfer and 4 weeks after rehabilitation to assess motor function at discharge. The FMA was developed to evaluate recovery from hemiplegic stroke [17]. It is divided into 5 domains: motor function, sensory function, balance, joint range of motion, and joint pain. Each domain contains multiple items, each scored on a 3-point ordinal scale (0 = cannot perform, 1 = performs partially, 2 = performs fully). The motor domain includes items measuring movement, coordination, and reflex of the shoulder, elbow, forearm, wrist and hand. The motor score ranges from 0 to a maximum of 66 for the UE. We also calculated the difference (Δ UE-FMA) by subtracting the UE-FMA at transfer from that at discharge. The Δ UE-FMA value reflects the degree of motor recovery after 4 weeks of rehabilitation.

BIA

BIA was performed using a portable BIA device (InBody S10; InBody Corp., Seoul, Korea) within 3 days of transfer to the stroke rehabilitation unit by a single trained physical therapist in the study center. Measurements were taken in a supine position. Body composition was evaluated under 4 categories: 1) soft tissue lean mass (SLM; kg), 2) phase angle at 50 kHz, 3) body fat mass (kg), and 4) body water (L). Segmental body composition analysis provides segmental measurement of SLM, phase angle and body water.

First, the SLM of whole body and segmental SLM on the affected and unaffected sides of UE were measured. SLM represents the total body water, protein, and non-osseous minerals. Thus, SLM is mostly composed of muscle mass, and represents the skeletal muscle mass within extremities [3]. We also calculated the difference (Δ SLM) by subtracting the SLM of affected side from that of the unaffected side. Second, the phase angle of whole body and segmental phase angle of the affected and unaffected sides of UE at 50 kHz were calculated from the impedance values. If the structural integrity of the cell membrane or cell function is high, the phase angle increases, and any plasma luminal structural damage of the cell decreases the phase angle. Therefore, we assumed that the phase angle of the affected side

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was smaller than that of the unaffected side, and calculated the difference (Δ Phase angle) between the 2 sides. Third, body fat mass was also measured. Finally, the whole-body water and segmental body water of the affected and unaffected sides were measured.

Statistical analysis

Data were analyzed using the Statistical Package for Social Sciences software package SPSS ver. 26.0 (SPSS Inc., Chicago, IL, USA). The distribution of body compositions measured by BIA was analyzed using descriptive statistics. Correlations between clinical measurements (Age, NIHSS, CCI, GNRI, BMI, Δ UE-FMA and UE-FMA at discharge) and body compositions measured by BIA was analyzed using Pearson correlation coefficient (for parametric data) and Spearman correlation coefficient (for nonparametric data). Simple linear regression analysis and stepwise multiple linear regression analysis were conducted to investigate the prognostic value of body composition measured via BIA with the UE-FMA at discharge and Δ UE-FMA. Residual analysis for the multiple linear regression model was performed, and then the hypothesis for normality, independence, and equal variance was satisfied. Body composition parameters used as independent variables were phase angle (whole body, affected side, unaffected side and differences between both sides), SLM (whole body, affected side, unaffected side and differences between both sides), body fat mass and body water (whole body, affected side and unaffected side). Other variables (sex, age, GNRI, BMI, UE-FMA at transfer, NIHSS and CCI) were also included. For multicollinearity, Variance Inflation Factor (VIF) was used, and VIF ≥ 10 was considered high correlation. A p value < 0.05 was used as the probability criterion for entry into the regression model.

RESULTS

Participant characteristics

The baseline characteristics of the study population are summarized (**Table 1**). Based on the screening of medical records, the body composition of 68 subjects diagnosed with stroke was measured using BIA, and 50 subjects met the eligibility criteria. All subjects belonged to the same ethnic group and were right-handed. The mean age was 62.1 years (range, 21–88 years) and included 20 males and 30 females. The types of stroke included cerebral infarction in 33 (66.0%) and cerebral hemorrhage in 17 (34.0%) cases. Days from onset was 10 to 47 days.

Relationship between body composition and clinical measurements

The distribution of body composition was represented using a boxplot (**Fig. 1**). Phase angle (whole body, affected side and unaffected side), SLM (whole body, affected side and unaffected side) and body water (whole body, affected side and unaffected side) were inversely correlated with age, and positively correlated with GNRI and BMI. But Δ Phase angle and Δ SLM were not significantly correlated with these clinical measurements. The CCI was inversely correlated with phase angle (whole body, affected side and unaffected side), SLM (whole body and unaffected side) and body water (whole body) (**Table 2**).

Predictive value of UE motor function

First, in Spearman correlation analysis, the Δ Phase angle showed a significant linear inverse correlation with UE-FMA at discharge for each sex (**Fig. 2A** for men, rho = −0.620, p = 0.004; **Fig. 2B** for women, rho = −0.556, p = 0.001). However, other variables including body fat mass, phase angle (affected side, unaffected side), SLM and body water was not significantly correlated with UE-FMA at discharge and Δ UE-FMA for each sex.

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Table 1. Baseline characteristics of subjects

Characteristics	Value (n = 50)
Sex, male/female	20/30
Age (yr)	62.1 (21–88)
NIHSS	5.7 (0–30)
CCI	5.3 (3–9)
Side of brain lesion	
Right	22 (44.0)
Left	28 (56.0)
Stroke pathology	
Infarction	33 (66.0)
Hemorrhage	17 (34.0)
Ischemic type (TOAST)	
Large-artery atherosclerosis	8 (24.3)
Small-artery occlusion	23 (69.7)
Cardio-aortic embolism	2 (6.0)
Other causes	0 (0)
Undetermined cause	0 (0)
Hemorrhagic type	
ICH	13 (76.4)
IVH	0 (0)
SAH	1 (6.0)
Mixed	3 (17.6)
Days from onset	21.3 (10–47)
MMSE score	23.3 (12–30)
MBI at transfer	43.6 (0–89)
UE-FMA at transfer	37.0 (0–66)
UE-FMA at discharge	46.7 (3–66)
Δ UE-FMA	9.7 (0–39)

Baseline values are presented as mean (percent) or mean (range).
BIA, bioelectrical impedance analysis; NIHSS, National Institute of Health Stroke; CCI, Charlson Comorbidity Index; ICH, intracerebral hemorrhage; IVH, intraventricular hemorrhage; SAH, subarachnoid hemorrhage; Days from onset, the period between the stroke onset and the BIA measurement date; MMSE, Mini-Mental State Exam; MBI, Modified Barthel Index; UE-FMA, Fugl-Meyer Assessment of upper extremity; Δ UE-FMA, the difference calculated by subtracting UE-FMA at transfer from UE-FMA at discharge.

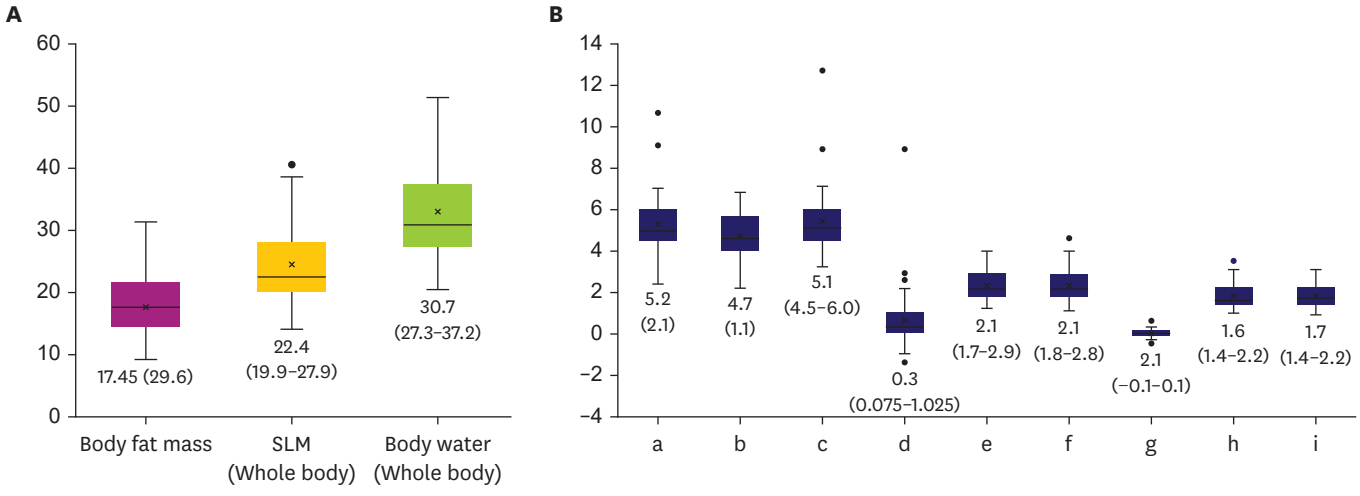

Fig. 1. Boxplots using descriptive statistics to analyze the distribution of body compositions. All results reported as means (standard deviation) for parametric data, as medians with 25th to 75th percentiles (interquartile range) for nonparametric data. (A) Body fat mass, SLM (whole body), body water (whole body). (B) a, phase angle (whole body); b, phase angle (affected side); c, phase angle (unaffected side); d, Δ Phase angle; e, SLM (affected side); f, SLM (unaffected side); g, Δ SLM; h, body water (affected side); i, body water (unaffected side).
SLM, soft tissue lean mass.

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Table 2. Correlations between clinical measurements and body compositions measured by BIA

Body compositions	Age*	NIHSS†	CCI†	GNRI*	BMI*
Body fat mass*	0.122	0.061	0.140	0.379§	0.649§
Phase angle (whole body)*	−0.592§	0.208	−0.555§	0.581§	0.544§
Phase angle (affected side)*	−0.521§	0.238	−0.454§	0.476§	0.311‡
Phase angle (unaffected side)†	−0.440§	0.338‡	−0.517§	0.397§	0.475§
Δ Phase angle†	−0.067	0.204	−0.059	0.055	0.261
SLM (whole body)†	−0.468§	0.112	−0.371§	0.508§	0.580§
SLM (affected side)†	−0.351‡	0.147	−0.265	0.456§	0.608§
SLM (unaffected side)†	−0.368§	0.156	−0.293‡	0.468§	0.626§
Δ SLM†	−0.130	0.112	−0.268	0.120	0.156
Body water (whole body)†	−0.436§	0.106	−0.326‡	0.475§	0.576§
Body water (affected side)†	−0.365§	0.155	−0.270	0.474§	0.616§
Body water (unaffected side)†	−0.355§	0.164	−0.266	0.450§	0.624§

BIA, bioelectrical impedance analysis; NIHSS, National Institute of Health Stroke; CCI, Charlson Comorbidity Index; GNRI, geriatric nutritional risk index; BMI, body mass index; Δ Phase angle, the difference calculated by subtracting the phase angle of the affected side from that of the unaffected side; SLM, soft tissue lean mass; Δ SLM, the difference calculated by subtracting the SLM of affected side from that of the unaffected side.
All data were shown as correlation coefficients. *Pearson's correlation coefficient (r) was utilized to establish the correlation among the parametric data; †Spearman's correlation analysis (rho) was utilized for nonparametric data.
‡p < 0.05, §p < 0.01.

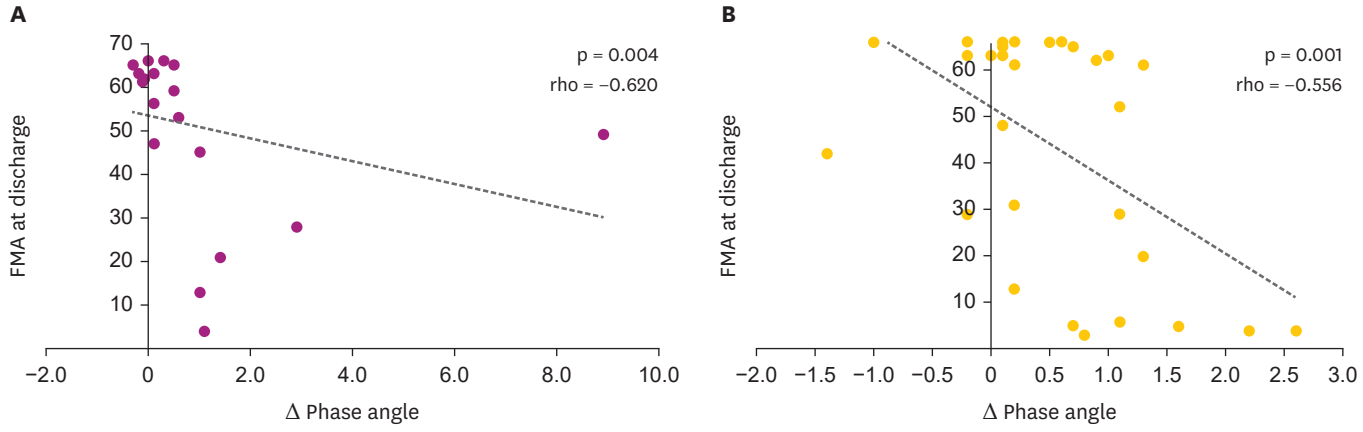

Fig. 2. Correlation between Δ Phase angle and UE-FMA at discharge for each sex. (A) Men; (B) Women.
FMA, Fugl-Meyer Assessment; UE-FMA, Fugl-Meyer Assessment of upper extremity; Δ Phase angle, the difference calculated by subtracting the phase angle of the affected side from that of the unaffected side.

Second, **Table 3** shows the results of the simple regression analysis with UE-FMA at discharge as the dependent variable and stepwise multiple linear regression analysis. When simple regression analysis with UE-FMA at discharge was performed, UE-FMA at transfer (β = 0.832, p < 0.01) and phase angle (affected side) (β = 7.654, p = 0.01) were significant predictors of UE-FMA at discharge. In simple regression analysis with Δ UE-FMA as the dependent variable, only UE-FMA at transfer and Days from onset were significant predictors of Δ UE-FMA. Multiple linear regression analysis with UE-FMA at discharge as the dependent variable (adjusted R^2 = 0.814) indicated that UE-FMA at transfer (β = 0.864, p < 0.01) and Days from onset (β = −0.35, p = 0.018) were significant predictors of UE-FMA at discharge. Other variables (age, sex, CCI, NIHSS, GNRI, BMI, body compositions measured by BIA) were originally included in analysis but not presented because of insignificant relationships with UE-FMA at discharge after controlling for the variables. The largest VIF was 1.053, indicating lack of multi-collinearity among variables. The UE-FMA at transfer was a stronger predictive variable than Days from onset (standardized β coefficient: UE-FMA at transfer = 0.929, Days from onset = −0.155). The coefficient of determination was 81.4%. When multiple regression analysis was performed with the Δ UE-FMA as the dependent variable, the result was the

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Table 3. Multiple linear regression analysis of variables predicting motor function of UE related to UE-FMA at discharge and Δ UE-FMA

Variables	Crude		Adjusted‡		
	β	p	β	p	Adjusted R^2
UE-FMA at discharge					0.814
UE-FMA at transfer	0.832	< 0.010†	0.864	< 0.010†	
Days from onset			−0.350	0.018*	
Phase angle (affected side)	7.654	0.010*			
Δ UE-FMA					0.205
UE-FMA at transfer	−0.168	0.007†	−0.136	0.025*	
Days from onset	−0.424	0.005†	−0.350	0.018*	

β, unstandardized coefficient; UE-FMA, Fugl-Meyer Assessment of upper extremity; Δ UE-FMA, the difference calculated by subtracting UE-FMA at transfer from UE-FMA at discharge; Days from onset, the period between the stroke onset and the bioelectrical impedance analysis measurement date.
*$p < 0.05$; †$p < 0.01$.
‡Results from stepwise method adjusted for age, sex, Charlson Comorbidity Index, body mass index, National Institutes of Health Stroke Scale, geriatric nutritional risk index, UE-FMA at transfer, Days from onset, body compositions measured by bioelectrical impedance analysis (phase angle, soft tissue lean mass, body water and body fat mass).

same, and only the adjusted R^2 value showed a difference ($R^2 = 0.205$). The largest VIF was 1.053, indicating lack of multi-collinearity among variables.

DISCUSSION

This study investigated the relationship between body composition measured by BIA and motor function and recovery of UE based on UE-FMA in patients with subacute stroke. We found that the Δ Phase angle of the UE had significant linear inverse correlation with motor function of UE at discharge in patients with subacute stroke. The larger the difference in the phase angles of both upper limbs measured after stroke, the smaller the UE-FMA at discharge value tended to be. This is the first study to evaluate the correlation and regression between body composition measured by BIA and motor function of UE based on UE-FMA in patients with subacute stroke. Considering the significant relevance found in this study, these findings suggest that the BIA have the potential of additional index to predict severity of upper limb motor function at discharge.

When simple regression analysis was performed with the UE-FMA at discharge as the dependent variable, the phase angle (affected side) was analyzed as a significant predictor. However, in multiple regression analysis, body compositions including phase angle measured by BIA were not found to be a significant predictor of upper limb motor function at discharge and motor recovery. The probable reason for this result may be that UE-FMA at transfer had stronger prediction power for UE-FMA at discharge than the phase angle and greatly implies the meaning of the phase angle [12]. When stepwise multiple regression analysis was performed with the remaining variables except for the UE-FMA at transfer, the phase angle (affected side) was analyzed as a significant predictor. While the phase angle value is less powerful index of upper limb motor function at discharge than the upper limb motor function at the time of transfer, it could be helpful in patients who could not cooperate with the muscle strength measurement due to cognitive dysfunction or poor general condition.

Recent studies have reported that phase angle of the whole body measured by BIA at the onset of stroke was independently associated with functional independence measure motor score at discharge [10,11]. These studies investigated the association of motor score in functional outcome, and the present study focused on upper limb motor function and recovery using FMA tool. Yoo et al. [13] found significant difference between impedance

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parameters measured by BIA between affected side and unaffected side of 5 severe stroke patients with upper limb hemiplegia. Although the small number of patients is a limitation of this study, it shows the potential of BIA as a clinically useful tool in stroke patients with upper limb hemiplegia.

Phase angle reflects quality of soft tissue [7] and muscle [18]. The subacute stage of hemiplegic stroke is associated with various muscle abnormalities that affect motor function [2]. Currently, the phase angle of the affected side reflects these effects. The main determinants of phase angle were age, sex and BMI [19], and analysis should be performed separately for male and female participants. In addition, underlying disease is also a determinant of phase angle [7]. For instance, there is a close correlation between phase angle and the state of liver disease [20]. The pathophysiology of disease may affect cell mass, cell membrane integrity, and cellular hydration, which can alter the phase angle. It has been reported that phase angle can detect nutritional risk in patients at hospital admission [8,21-23]. Phase angle is an index that can be affected by various clinical situations that can lead to fluid imbalance. In the present study, phase angle correlated with age, CCI and GNRI. This is consistent with the characteristics of phase angle. In this study, the bilateral difference, not the absolute value of the phase angle of the affected side of the UE, was related to motor recovery. Therefore, it is thought to exclude the effect of underlying disease and reflect the change in hemiplegia due to stroke.

Hemiplegic stroke leads to structural adaptive changes in muscle tissue with a combination of denervation, disuse, remodeling and spasticity, and was predicted to be most pronounced during the early and subacute phase after a stroke [2,24]. We predict that the phase angle reflected these changes of muscles of affected side in hemiplegic stroke patients. In patients with good initial motor function, these muscle changes were less on the affected side, and patients with poor initial motor function more severe on the affected side. Therefore, it is thought that the greater the difference between the initial bilateral phase angle values, the more decreased the motor function at discharge. Further studies investigating the phase angle cutoff value in stroke patients are needed before it can be used as a prognostic tool.

The study has several limitations. First, the retrospective study design and the relatively small sample size based on a single center may decrease the statistical power. Second, because the BIA date was heterogenous for each patient, it is possible that the motor function measured 4 weeks after transfer was affected by spontaneous motor recovery over time. Third, it is recommended to follow up motor recovery after 3 or 6 months from the time of transfer, but only the results after 4 weeks were used in this study. Finally, since our study investigated only the motor recovery of the upper extremities, further studies involving the lower extremities are needed.

CONCLUSIONS

The Δ Phase angle, the difference calculated by subtracting the phase angle of the affected side from that of the unaffected side measured by BIA showed significant linear inverse correlation with motor function of UE at discharge. However, for future use of phase angle as an additional index in predicting upper limb motor recovery after stroke, further studies are needed.

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