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Original Article

Analysis of Phase Angle and Balance and Gait Functions in Pre-Frail Individuals: A Cross-Sectional Observational Study

Daisuke Homma[a,b]*, Izumi Minato[c], Norio Imai[d], Dai Miyasaka[e],
Yoshinori Sakai[f], Yoji Horigome[d], Hayato Suzuki[a], Yoichiro Dohmae[e], and Naoto Endo[g]

Divisions of [a]Orthopaedic Surgery, [d]Comprehensive Musculoskeletal Medicine,
Niigata University Graduate School of Medical and Dental Sciences, Niigata 951-8510, Japan,
[b]Department of Rehabilitation, [e]Division of Orthopaedic Surgery, Niigata Bandai Hospital, Niigata 950-8534, Japan,
[c]Division of Orthopaedic Surgery, Niigata Rinko Hospital, Niigata 950-8725, Japan,
[f]Division of Orthopaedic Surgery, Niigata City General Hospital, Niigata 950-1197, Japan,
[g]Division of Orthopaedic Surgery, Niigata Prefectural Tsubame Rosai Hospital, Tsubame, Niigata 959-1228, Japan

We measured the muscle mass and phase angle of each body part to evaluate the relationship between balance and gait functions in individuals with a pre-frailty status. This cross-sectional observational study determined the skeletal muscle mass-to-body weight ratio and phase angles of 21 control (robust) and 29 pre-frail subjects. Their Brief-Balance Evaluation Systems Test, Timed Up-and-Go (TUG) test, Life-Space Assessment, and Modified Fall Efficacy Scale scores plus the relationship between muscle mass, phase angle, and motor function were evaluated. In the pre-frailty group (three males, 26 females, aged 75.58 ± 7.60 years), significant correlations were noted between the Brief-Balance Evaluation Systems Test score and lower-limb ($r = 0.614$) and whole-body ($r = 0.557$) phase angles, and between the TUG test score and lower-limb muscle mass-to-body weight ratio ($r = -0.616$), lower-limb phase angle ($r = -0.616$), and whole-body phase angle ($r = -0.527$). Evaluating the phase angle of the lower extremities of pre-frail patients and intervening accordingly may help clinicians maintain and improve these patients' balance and gait functions.

Key words: bioelectrical impedance analysis, motor function, muscle quality, muscle volume

The world's population is aging. According to a United Nations report [1], the number of people aged ≥ 65 years is expected to increase from 700 million to 1 billion by 2050, with the global total expected to rise to 1.5 billion (16%). With an aging population, people who are ≥ 65 years old may have difficulty with self-care, independent living, and walking, and these developments are expected to increase the burden on healthcare systems [2]. It has also been suggested that the number of disability-adjusted life years for people aged ≥ 60 years will increase by 55% between 2004 and 2030 [3]. It is thus important to promote healthy aging in part to reduce medical costs and maintain or improve the quality of life of all individuals.

The concept of frailty has been reported in association with population aging. Frailty is an intermediate state of reduced homeostasis in response to stress (falling between a robust state and a state requiring nursing care [4]) that increases the risk of health problems [5]. Since frailty is reversible, effective prevention and interventions are important. Frail and pre-frail stages are composed of multifaceted elements, including mental, psychological, social, and physical factors [6]. Physical

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*Corresponding author. Phone : +81-25-244-4700; Fax : +81-25-247-6216
E-mail : daisukehomma24@gmail.com (D. Homma)

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frailty is associated with falling [7], which leads to trauma such as bone fractures; a detailed assessment and prompt intervention for physical frailty are therefore necessary. However, a person in an advanced stage of frailty may have several diseases associated with aging, and recovery is not easy. The implementation of early prevention and recovery measures in the pre-frail stage is thus needed.

A pre-frail stage can cause a decline in an individual's physical function, walking ability, and balance function [8]. It has been suggested that the early detection of the pre-frail stage may provide an opportunity for effective management to prevent falls [9]. Changes in the physical function of pre-frail individuals may cause muscle changes, such as sarcopenia. However, since it is not possible to identify precisely which part(s) of the body are experiencing muscle changes, it is necessary to examine muscle degeneration in each body part, and interventions should be tailored towards addressing changes in muscle quantity and quality.

Sarcopenia should be evaluated by using a combined approach to muscle quantity and quality, and muscle mass can be measured using bioelectrical impedance methods [10]. It was recently suggested that poor muscle quality can lead to adverse health outcomes [11]. A simple and objective indicator of muscle quality is the phase angle, which is calculated using the reactance and resistance values in bioelectrical impedance, which reflect the physiological function of the cell membrane. Since the phase angle decreases with age and is related to muscle strength and physical function [12,13], it is possible that individuals with good phase angles have excellent muscle quality and high motor functions.

The phase angle of the whole body has been measured [14,15], but the phase angle of isolated areas of the body such as the upper and lower limbs has not been examined. We hypothesized that in pre-frail individuals, changes in the phase angle and muscle mass may occur in isolated parts of the body and may be related to motor functions such as balance and gait ability. Determining the relationships among the muscle mass, phase angle, and motor function in each pre-frail body part may be useful for interventions designed to prevent and counteract physical frailty. We conducted the present study to (*i*) measure the muscle mass and phase angle of isolated body parts in pre-frail participants, and (*ii*) examine the relationship between balance and gait functions.

Materials and Methods

Study design. This was a cross-sectional observational study, and the study period spanned from August to November, 2019. Volunteers were recruited from in and around Niigata City, Japan. Because the elderly subjects were recruited from the community, it was difficult to ascertain each subject's history and current medical conditions; however, all subjects were able to walk unassisted and had the physical capability to perform each task. The degree of frailty of each participant was evaluated using the Japanese version of the Cardiovascular Health Study (JCHS) criteria [16]. Among the 52 participants who were aged ≥65 years and for whom all measurement items were confirmed, two patients (one with measurement error and another diagnosed as frail by the JCHS criteria) were excluded. As a result, a total of 50 participants (21 in the robust group and 29 in the pre-frail group) were enrolled in this study. The control (robust) group consisted of two men and 19 women, and the pre-frail group consisted of three men and 26 women.

This study was conducted in accord with the principles of the Declaration of Helsinki and was approved by the Ethics Committee of Niigata Bandai Hospital (approval no. 74). The participants were informed about the study in detail both verbally and in writing, and written informed consent was obtained from each participant before the study was conducted.

Assessment of clinical parameters. For each of the subjects in the control and pre-frailty groups, we determined the skeletal muscle mass-to-body weight ratio (skeletal muscle mass divided by body weight in kg × 100: %BW), the skeletal muscle mass index (SMI), and the phase angles of the upper extremities, lower extremities, and whole-body. Motor function was assessed via the Brief-Balance Evaluation Systems Test (Brief-BESTest) and Timed Up and Go (TUG) test. Life-space variability was assessed using the Life-Space Assessment (LSA), and fear of falling was assessed using the Modified Fall Efficacy Scale (MFES).

1. Physical evaluation: Muscle mass, skeletal muscle index, and phase angles

The subjects' muscle mass, phase angles, and SMI were measured using a multi-frequency 8-electrode body composition analyzer (MC-780A-N, Tanita, Tokyo) (Fig. 1), a bioelectrical impedance device that measures electrical resistance by applying a weak alter-

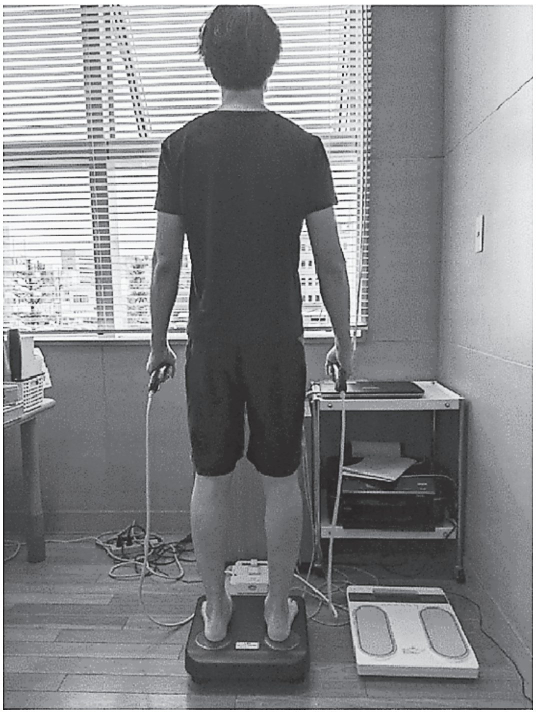

Fig. 1 Limb imaging using the bioelectrical impedance method. A multi-frequency 8-electrode body composition analyzer (MC-780A-N, Tanita, Tokyo) was used. Measurements were obtained with the subjects standing with their bare feet on the toe and heel electrodes, arms hanging several centimeters away from the body (or waist), and hands grasping the hand grips.

nating current <90 μA to the body. Measurement frequencies of 5, 50, and 250 kHz were used to directly measure the extracellular and intracellular water content of the subject's body. Since this body composition analyzer can determine individual impedances in each segment using the 8-electrode method, the bone muscle mass was calculated separately for the upper and lower limbs and the whole body. The muscle mass was calculated as the weight of tissue (excluding fat and estimated bone mass) divided by body weight and normalized.

The SMI was also calculated using the same measurements and by dividing the sum of the skeletal muscle mass of the extremities (measured by the body composition meter) by the square of the subject's height (m^2) (kg/m^2). Figure 2 describes the calculation of the phase angle based on reactance (Xc) and resistance (R) at 50 kHz, as described [13, 17].

The phase angle was calculated for each body part in the same way as the muscle mass; the average of the

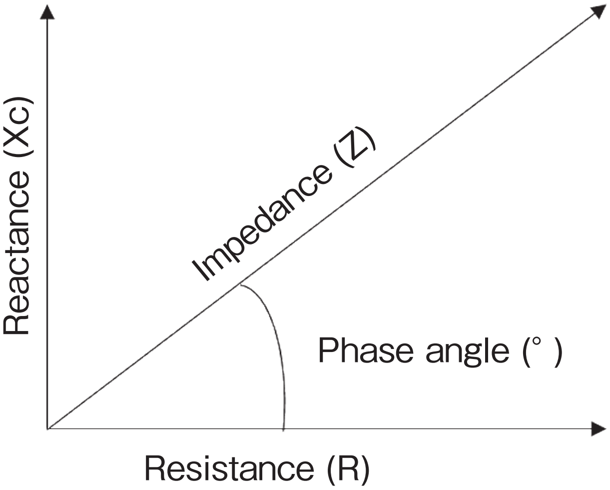

Fig. 2 Diagram of phase angle calculation. The phase angle was calculated using the following equation: phase angle (°) = [arc tangent (Xc/R) × (180/π)] with resistance (R), reactance (Xc), and impedance (Z). Absolute values were used for the phase angle.

phase angles of the left and right upper and lower limbs, and that of the phase angles of the right and left halves of the body, was taken to calculate the phase angle of the upper and lower limbs and that of the whole body.

2. Evaluation of motor function: The Brief-BESTest and TUG test

The Brief-BESTest is an evaluation scale for balance function developed by Padgett *et al.* [18] as a shortened version of the BESTest, which was devised by Horak *et al.* [19]. The Brief-BESTest was developed by extracting one item from each of the following elements: biomechanical constraints, stability limits, predictive postural control, reactive postural control, sensory function, and gait stability; it can be used to evaluate balance function in a simple and multifaceted manner. Eight movement tasks with six items are evaluated on a scale of 0-3 points, with a maximum score of 24 points. Since the measurement items are identical to those of the BESTest, the measurement method used herein is similar to that used in previous studies [18].

The TUG test was developed by Podsiadlo and Richardson [20]. The subjects were instructed to stand up from a standard chair, walk to a point on the floor 3 m away from the chair, and then return to the chair again, all as quickly as possible; the time to complete the task was recorded. The TUG test is an assessment item on the Brief-BESTest, but since the TUG time is converted into a score in the Brief-BESTest, the actual measurement was recorded as an independent evaluation of gait function.

3. Questionnaire evaluation

In accord with previous studies, the subjects' fear of falling was assessed using the MFES [21], and their physical activity was assessed by the LSA [22]. The MFES is a 14-item questionnaire in which the respondent rates his or her fear of falling on a scale of 0 (not confident at all) to 10 (completely confident) for each question.

The LSA is an assessment scale used to evaluate indoor and outdoor daily activities. With the LSA, a score is calculated based on the frequency and range of the subject's activities and the degree of independence of each activity in the previous month, with a maximum score of 120 points. The range of activities is classified into six levels, from the bedroom to outside in the respondent's community. In the present study, the LSA scores were calculated using the presence or absence of going out, the frequency of going out, the degree of independence, and the total score in each activity range was obtained.

Statistical analyses. The Shapiro-Wilk test was used to check the data distribution for all of the measurement items. A two-sample *t*-test (Mann–Whitney test) was used to determine the characteristics of pre-frailty. The significance level was set at $p < 0.05$. Pearson's and Spearman's rank correlation coefficients were calculated based on the analysis of the data to examine the relationships among muscle mass, phase angles, and motor function in the pre-frailty group. The Bonferroni correction was used to examine the correlation, and the significance level was set at $p < 0.008$. The statistical analyses were performed using SPSS ver. 21 (IBM Corp., Armonk, NY, USA).

Results

The average ages of the subjects in the pre-frailty and control (robust individuals) groups were 75.58 ± 7.60 and 71.47 ± 4.50 years, respectively. There was no significant difference between the two groups in terms of muscle mass. However, the lower-limb phase angle of the control group was 4.25 ± 0.75°, while that of the pre-frailty group was significantly decreased at 3.80 ± 0.62°. The whole-body and upper limb phase angles were not decreased in the pre-frailty group. Significantly lower Brief-BESTest scores and significantly slower TUG test times were observed in the pre-frailty group compared to the control group (Table 1).

In the control group, the Brief-BESTest and TUG scores were not significantly correlated with each physical function. However, in the pre-frailty group, the

Table 1 Basic characteristics of participants

	Control (robust)	Pre-frailty	Difference
Age (years)	71.47 ± 4.50	75.58 ± 7.60	0.021*
Height (cm)	152.89 ± 6.90	151.98 ± 4.97	0.883†
Body weight (kg)	53.31 ± 11.55	52.90 ± 8.27	0.658†
Upper limb muscle-weight ratio (%body weight)	6.01 ± 0.76	5.85 ± 0.77	0.486
Lower limb muscle-weight ratio (%body weight)	23.21 ± 2.86	22.17 ± 2.51	0.180
Whole body Muscle-Weight Ratio (%body weight)	65.56 ± 6.95	63.98 ± 6.95	0.743
Upper limb Phase Angle (°)	5.01 ± 0.47	5.04 ± 0.60	0.857
Lower limb Phase Angle (°)	4.25 ± 0.75	3.80 ± 0.62	0.026*
Total body Phase Angle (°)	4.68 ± 0.48	4.52 ± 0.58	0.287
SMI (kg/m^2)	6.50 ± 0.90	6.30 ± 0.60	0.969†
male (SMI < 7.0)	0	2	
female (SMI < 5.7)	0	1	
BBT	21.40 ± 2.37	16.62 ± 4.98	< 0.001†*
TUG	6.70 ± 1.22	8.11 ± 2.16	0.014*
LSA	105.14 ± 12.89	96.65 ± 21.74	0.259†
MFS	136.28 ± 6.10	124.03 ± 29.84	0.509†

†: Mann–Whitney *U* test; no mark: two-sample *t*-test; *$p < 0.05$.

SMI, skeletal muscle mass index; MFES, Modified Falls Efficacy Scale; BBT, Brief-BESTest; TUG, Timed up and go test; LSA, Life-Space Assessment.

Brief-BESTest was significantly correlated with the lower-limb (r = 0.614) and whole-body (r = 0.557) phase angles. There were also significant correlations between the TUG test times and the lower-limb muscle mass-to-body weight ratio (r = −0.616), lower-limb phase angle (r = −0.616), and whole-body phase angle (r = −0.527) in the pre-frailty group (Table 2).

In the pre-frailty group, lower-extremity and whole-body phase angles were associated with the Brief-BESTest score, and the lower-extremity and whole-body phase angles and lower-extremity muscle mass were associated with the TUG test time. The lower-extremity phase angle was associated with the Brief-BESTest and TUG test results and had the highest correlation. These results demonstrate that (*i*) compared to the subjects' muscle mass, the phase angle was more closely related to their motor function, and (*ii*) the lower-limb phase angle had the highest correlation with motor functions.

Discussion

To the best of our knowledge, this study is the first to evaluate the regional muscle mass and phase angle in pre-frail individuals. The main findings of this study show that the lower-limb phase angle, balance function, and TUG test time were decreased in pre-frail individuals. The phase angle of the lower extremities was correlated with balance function and the TUG time and had a higher correlation with motor functions than the other items.

Regarding the phase angle values, our analyses revealed that the whole-body phase angles of the subjects in the control and pre-frailty groups were 4.68 ± 0.48° and 4.52 ± 0.58°, respectively. Ninety percent of the subjects in the control and pre-frailty groups were women, and we thus compared our results with those of previous investigations of women. In 2019, Yamada *et al.* measured the phase angle of older people in Japan and reported that it was 3.81° in women with the average age of 80.4 years [13]. Another report observed that the phase angle was 4.2 ± 0.77° in individuals aged 77.5 ± 7.8 years [23]. However, it is well known that the phase angle decreases with age. The mean ages of patients in the present study's pre-frail and control groups were 75.58 and 71.47 years, respectively, which are lower than those in the previous studies [13, 23]. It is thus reasonable that the phase angle obtained in this study is higher than those reported [13, 23].

Regarding the characteristics of the present pre-frailty group, the subjects' physical and motor functions were characterized by significant decreases in the Brief-BESTest result, TUG time, and lower-limb phase angle compared to those of the control group. However, there were no significant differences in the lower-limb muscle mass, LSA, or MFES between the groups. These results indicate that the pre-frailty group had lower gait and balance functions but no change in the fear of falling or the range of physical activity, suggesting a lack of fear and a higher risk of falling. It has been suggested that frailty and pre-frailty may cause a decline in physical, gait, and balance functions [8]. Similar to previous studies, the our subjects exhibited impaired

Table 2 Relationships among the results of the Brief-BESTest, Timed Up-and-Go test, phase angles, and muscle mass

Participants	Test	r/*p*	Upper limb muscle: weight ratio	Lower limb muscle: weight ratio	Body muscle: weight ratio	Upper limb phase angle	Lower limb phase angle	Body phase angle
Control	BBT	r	0.152†	0.142†	0.029†	0.234†	0.296†	0.289†
		p	0.511	0.540	0.900	0.306	0.193	0.204
	TUG	r	0.035	−0.068	0.124	−0.386	−0.345	−0.445
		p	0.882	0.769	0.591	0.084	0.126	0.043
Pre-frailty	BBT	r	0.291	0.425	0.184	0.459	0.614	0.557
		p	0.126	0.022	0.339	0.012	<0.001*	0.002*
	TUG	r	−0.480	−0.616	−0.444	−0.394	−0.616	−0.527
		p	0.008	<0.001*	0.016	0.034	<0.001*	0.003*

†Spearman's rank correlation coefficient; $^{*}p < 0.008$ (Bonferroni correction 0.05/6); no mark, Pearson's correlation coefficient.
BBT, Brief-BESTest; TUG, Timed up and go test; r, correlation coefficient; *p*, *p*-value.

gait and balance functions. We therefore believe that it is important to assess older individuals' physical functions related to falls and intervene accordingly.

We hypothesized that changes in the phase angle and muscle mass might occur in isolated areas of the body and be related to motor functions such as balance and walking ability, and we thus measured the muscle mass and phase angle in the pre-frailty. The three types of muscle degeneration are dynapenia, pre-sarcopenia, and sarcopenia. Sarcopenia and pre-sarcopenia cause a loss of skeletal muscle mass, and dynapenia is defined as age-related muscle weakness [24] and is considered a condition in which muscle function and quality deteriorate with or without the loss of skeletal muscle mass [25]. In the present investigation, the subjects in the pre-frailty group showed no change in the lower-limb muscle mass, but their lower-limb phase angle, balance function, and TUG times (which reflect many lower-limb functions) were decreased, suggesting that the pre-frailty group had lower limb-centered dynapenia.

The muscle function of the lower limbs declines earlier than that of the upper limbs [26]. Similarly, the present pre-frailty group did not show a decrease in upper- or lower-limb muscle mass or the upper-extremity phase angles, suggesting that the degree of aging or pathological atrophy may vary by body region. We thus believe that assessing the muscle mass and phase angle by body region is more accurate than assessments of the entire body. In terms of the relationships among motor function, muscle mass, and phase angle, the Brief-BESTest involves the lower-limb and whole-body phase angles, while the TUG test involves the lower-limb muscle mass-to-body weight ratio and the lower-limb and whole-body phase angles.

Although the lower-limb and whole-body phase angles were commonly related to Brief-BESTest and TUG test results, our analyses revealed that the correlation coefficient of the lower-limb phase angle was higher than that of the whole-body phase angle. If only the phase angle and muscle mass of the whole body are evaluated, it would be difficult to determine which part or parts of the body are abnormal, and it would be more difficult to devise effective interventions. These results suggest that (*i*) the lower-limb phase angle is more strongly related to motor functions, such as balance and gait, than the whole-body and upper-limb phase angles, and (*ii*) evaluating the lower-limb phase angle and intervening accordingly may be effective.

Regarding clinical applications of these findings, interventions focusing on the phase angle of the lower extremities is expected to improve balance and gait functions and may be effective in preventing falls. It has been reported that the phase angle can be improved by aerobic exercise [27] and resistance training [28], and that the quality of the skeletal muscle can be improved by a combination of exercise and protein intake [29]. Thus, to maintain and improve the balance and gait functions of pre-frail patients, effective interventions may include aerobic exercise and resistance training, especially of the lower limbs, the assessments of muscle mass and phase angle in each region, plus active protein intake.

Our study has several limitations. The participants could not be categorized or analyzed by gender or compared to frail individuals. The number of subjects was small and the analysis was conducted for mixed genders. In order to conduct a more detailed investigation of individuals with pre-frailty, it will be necessary to increase the number of subjects, examine the differences in phase angles between men and women, and analyze the relationship between phase angles and motor function for each gender.

In addition, we could not rule out the influence of confounding factors such as musculoskeletal diseases related to the lower extremities, as we could not confirm a detailed history of the subjects' disease status. Although this study had a small number of subjects, we consider the data valuable because the robust and pre-frailty groups were both comprised of subjects who had the physical ability to walk unassisted, and the analyses demonstrated a between-group difference in lower-extremity phase angle values. However, locomotor diseases and other conditions may affect motor function, muscle mass, and phase angles, and thus further analyses of more subjects that take confounding factors into account are needed.

In conclusion, the limb phase angle and balance and gait functions were decreased in the pre-frailty group compared to the control group. Evaluations of lower-limb phase angles may be applicable in assessments of aging phenomena such as dynapenia, and it may be important to evaluate each limb individually. Several studies have evaluated the phase angle of the whole body, and we believe that the importance of evaluating the phase angle of each body part for different purposes will increase in the future. Evaluations of the lower-limb phase angle and intervening accordingly may be effective in maintaining and improving balance and gait functions in pre-frail individuals.

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