J Nutr Health Aging. 2019;23(3):251-255

PHASE ANGLE IS A USEFUL INDICATOR FOR MUSCLE FUNCTION IN OLDER ADULTS

M. YAMADA[1,2], Y. KIMURA[1], D. ISHIYAMA[1], N. NISHIO[1], Y. OTOBE[1], T. TANAKA[1], S. OHJI[1], S. KOYAMA[1], A. SATO[1], M. SUZUKI[1], H. OGAWA[1], T. ICHIKAWA[1], D. ITO[1], H. ARAI[2]

1. Graduate School of Comprehensive Human Sciences, University of Tsukuba, 3-29-1 Otsuka, Bunkyo-ku, Tokyo 112-0012, Japan; 2. National Center for Geriatrics and Gerontology, 7-430, Morioka-cho, Obu, Aichi 474-8511, Japan. Corresponding author: Minoru Yamada, Graduate School of Comprehensive Human Sciences, University of Tsukuba, 3-29-1 Otsuka, Bunkyo-ku, Tokyo 112-0012, JapanTel: +81-3-3942-6863, Fax: +81-3-3942-6895, Email address: m-yamada@human.tsukuba.ac.jp

Abstract: *Aim:* Phase angle (PhA) can be determined through bioelectrical impedance analysis and is a unique variable for skeletal muscle. The objective of this study was to evaluate the relationship between PhA and muscle mass/quality in older adults. In addition, we attempted to determine the cutoff value of PhA for poor muscle function. *Methods:* Community-dwelling Japanese older men (n=285, 81.1±7.1 years) and women (n=724, 80.4±6.8 years) participated in this study and were classified into four groups based on the Asian Working Group for Sarcopenia (normal, presarcopenia, dynapenia, and sarcopenia). We measured PhA using bioelectrical impedance analysis, muscle quantity and quality indicators using ultrasonography, muscle strength, and physical performance and compared them in four groups. We also tried to determine the cutoff value of PhA for poor muscle function. *Results:* We found a significant difference in PhA among the four groups in men ($P<0.05$), and the dynapenia (3.61±0.75°) and sarcopenia groups (3.40±0.74°) showed significantly lower values than the normal group (4.50±0.86°) ($P<0.05$), but not the presarcopenia group (4.12±0.85°). In women, a significant difference was also observed among the four groups ($P<0.05$), and the dynapenia (3.41±0.65°) and sarcopenia groups (3.31±0.66°) showed significantly lower measures than the normal group (4.14±0.71°) ($P<0.05$), but not the presarcopenia group (4.07±0.51°). The receiver-operating characteristic curve analysis indicated the best cutoff value of PhA (men: 4.05°, women: 3.55°) to discriminate sarcopenia and dynapenia from normal and presarcopenia. *Conclusion:* These findings suggest that PhA is a useful indicator for muscle function.

Key words: Bioelectrical impedance, dynapenia, older adults, phase angle, sarcopenia.

Introduction

Phase angle (PhA) can be measured using bioelectrical impedance analysis and is a unique measure for skeletal muscle. PhA is one of the indicators for cell membrane structure, and a lower PhA suggests decreased cellular integrity (1-3). Indeed, a lower PhA is correlated to poor muscle function, such as low muscle strength and volume (4-6). Previous studies also indicated that PhA is not only related to muscle function but also to gender, age, nutritional status, and mortality (7-12).

Sarcopenia and dynapenia are serious degenerative changes in skeletal muscle. Age-dependent decrease of muscle structure and function is closely related to adverse health outcomes, such as falls, hospitalization, disability, and death (13-17). Our previous studies found that sarcopenic and dynapenic older adults had common characteristics: significant qualitative changes in skeletal muscle and lower concentration of plasma leucine, branched-chain amino acids, and essential amino acids (18, 19). The management of these changes in age-related skeletal muscle in older adults is very important to consider.

Recently, researchers have proposed PhA as a good indicator for sarcopenia (5, 20). Interestingly, PhA shows an age-dependent change and a decrease according to the progression of sarcopenia severity (from normal to presarcopenia, sarcopenia, and severe sarcopenia) (5, 20). However, there is no study for PhA in dynapenic older adults, and the values of PhA in both sarcopenic and dynapenic older adults are not yet well addressed.

The objective of this study, therefore, was to evaluate the relationship between PhA and sarcopenia classification (normal, presarcopenia, dynapenia, and sarcopenia). In addition, we attempted to determine the cutoff value of PhA for poor muscle function. We hypothesized that both sarcopenic and dynapenic older adults would show a lower PhA. We also sought to determine the cutoff value of PhA using receiver operation characteristics (ROC) analysis.

Methods

Participants

Participants were recruited through an advertisement in the local press and a poster at the senior center. We recruited community-dwelling older adults in Japan. The inclusion criteria included individuals aged 65 years and older with the ability to walk independently (including with a cane). The exclusion criteria were stroke, Parkinson's disease, severe cognitive impairment, severe psychiatric impairment, and severe cardiac, pulmonary, or musculoskeletal disorders. In addition, we excluded older adults with artificial implants, such as cardiac pacemakers and joints, which did not permit the measurement of bioelectrical impedance. This study was

Received September 19, 2018
Accepted for publication October 23, 2018
Published online December 12, 2018, http://dx.doi.org/10.1007/s12603-018-1151-0

conducted in accordance with the guidelines proposed by the Declaration of Helsinki, and the study protocol was reviewed and approved by the Ethics Committee of Tsukuba University Graduate School of Comprehensive Human Sciences.

Outcome measures

Bioelectrical impedance

A bioelectrical impedance data acquisition system (MC-780A; TANITA Co, Ltd, Tokyo, Japan) was used to determine bioelectrical impedance. This system uses electrical current at different frequencies (5, 50, and 250 kHz) to directly measure the amount of extracellular and intracellular water in the body. Participants stood on two metallic electrodes and held metallic grip electrodes. We calculated PhA and muscle mass using these bioelectrical impedance data.

PhA was defined by the following equation: PhA (°)=arctangent (reactance (Xc)/resistance (R)) × (180/π). Reactance and resistance of 50 kHz were used to calculate PhA. In addition, using the segmental skeletal muscle mass, a value for the leg skeletal muscle mass (kg) and appendicular skeletal muscle mass (kg) were determined. By dividing the muscle weight by height squared (kg/m2), the skeletal muscle mass was converted into the leg skeletal muscle mass index (SMI).

Measurement of echo intensity in the thigh muscle

An ultrasound device (ProSound2, Hitachi-Aloka Medical, Tokyo, Japan) with a 7.5-MHz linear-array probe was used to obtain the ultrasound images of the rectus femoris and vastus intermedius. The ultrasonography setting was consistently set at 44 dB dynamic range and 68 dB gain. The ultrasound images recorded in the two trials were averaged as the representative for analysis. Furthermore, we assessed the muscle thickness and echo intensity of the quadriceps femoris muscle. The muscle thickness is a muscle quantity indicator, whereas the echo intensity is a muscle quality indicator. The detailed description of the measurement of echo intensity has been previously described (18).

Physical assessment

For physical performance, we measured the 5-m walking speed and grip strength. Both measurements were performed by physical therapists who received a lecture for the correct protocols for both measures from a well-trained investigator before the study started. Each measure was recorded twice and averaged as the representative value.

Definition of sarcopenia classification

We defined sarcopenia classification using the diagnostic algorithm formulated by the Asian Working Group for Sarcopenia (21). Sarcopenia was defined as the presence of both low muscle mass (low SMI) and low physical function (low physical performance or low muscle strength) (21). According to the suggestion of the European Working Group on Sarcopenia in Older People, presarcopenia was defined as low muscle mass without low physical function (22). Finally, dynapenia was operationally defined as low muscle function without low muscle mass. This sarcopenia classification was used in our previous study (18, 19).

Statistical analysis

The general linear model was used for univariate and multivariate analyses to assess the differences in PhA among the four groups (normal, presarcopenia, dynapenia, and sarcopenia). Then, a post hoc test was performed using a Bonferroni test to assess which group differed significantly from the others. We also performed multivariate analyses for PhA by adjusting for age. The relationship between PhA and grip strength, walking speed, echo intensity and muscle thickness of quadriceps femoris muscle was analyzed using the Pearson correlation coefficient.

ROC curves and areas under the curve (AUCs) were used to determine the cutoff values of PhA on sarcopenia. Similarly, ROC curves and AUCs were used to determine the cutoff value of PhA in the combination of sarcopenia and dynapenia. The cutoff value for maximizing the sensitivity and specificity for each analysis was calculated using the Youden index.

In all statistical analyses, the same analyses were repeated for each gender separately. The data were managed and analyzed using SPSS (Statistical Package for the Social Sciences, Windows version 25.0; SPSS, Inc., Chicago, IL, USA). A p value less than 0.05 was considered to indicate statistical significance for all analyses.

Results

The characteristics of the study participants are shown in Table 1. The mean age was 81.1±7.1 years in men (n=285) and 80.4±6.8 years in women (n=724). The mean PhA for men and women was 3.96±0.93° and 3.81±0.76°, respectively. The proportion of normal, presarcopenia, dynapenia, and sarcopenia was 38.6% (n=110), 9.8% (n=28), 30.2% (n=86), and 21.4% (n=61) in men and 44.3% (n=321), 13.7% (n=99), 27.5% (n=199), and 14.5% (n=105) in women, respectively.

The mean PhA of normal, presarcopenia, dynapenia, and sarcopenia was 4.50±0.86°, 4.12±0.85°, 3.61±0.75°, and 3.40±0.74° in men and 4.14±0.71°, 4.07±0.51°, 3.41±0.65°, and 3.31±0.66° in women, respectively. A significant difference was observed for PhA among the four groups in men (univariate: F=32.23, P<0.01, multivariate: F=7.54, P<0.01), and the dynapenia and sarcopenia groups showed significantly lower values of PhA than the normal group according to multivariate analysis (P<0.05) (Figure 1A). In women, a significant difference was also observed for PhA among the four groups (univariate: F=75.27, P<0.01, multivariate: F=20.25, P<0.01), and the dynapenia and sarcopenia groups showed significantly lower values of PhA than the normal and presarcopenia groups using multivariate analysis (P<0.05)

(Figure 1B). In both sexes, no significant difference was found for PhA between the dynapenia and sarcopenia groups. In addition, the proportion of sarcopenia and dynapenia was closely related with PhA in both sexes (Figure 2A, B).

Table 1
Characteristics of the study participants

	Men n=285		Women n=724		P-value
	Mean	SD	Mean	SD	
Characteristics					
Age	81.1	(7.1)	80,4	(6.8)	**0.172**
Height, cm	161.8	(6.7)	149,0	(6.4)	<0.001
Weight, kg	59.2	(8.8)	49,2	(7.9)	<0.001
Body fat, %	21.8	(7.3)	29,4	(8.2)	<0.001
BMI, kg/m2	22.6	(2.8)	22,1	(3.4)	0.034
Muscle indicators					
Phase angle	3.96	(0.93)	3,81	(0.76)	0.010
Leg SMI, kg/m^2	5.77	(0.90)	4,80	(0.70)	<0.001
SMI, kg/m2	7.45	(1.04)	6,14	(0.85)	<0.001
QF thickness, cm	2.97	(0.76)	2,47	(0.60)	<0.001
QF echo intensity	42.7	(9.8)	45,5	(11.0)	<0.001
Knee extension torque, Nm	61.0	(26.1)	48,8	(18.1)	<0.001
Knee extension torque, Nm/kg	1.04	(0.40)	1,01	(0.35)	0.306
Physical performance					
5m usual walking speed, m/sec	1.04	(0.34)	1,11	(0.34)	<0.001
Grip strength, kg	27.5	(6.7)	19,3	(4.3)	<0.001
Sarcopenia category					
Normal, n (n)	110	(38.6)	321	(44.3)	0.015
Pre-sarcopenia, n (%)	28	(9.8)	99	(13.7)	
Dynapenia, n (%)	86	(30.2)	199	(27.5)	
Sarcopenia, n (%)	61	(21.4)	105	(14.5)	

BMI: body mass index, SMI: skeletal muscle mass index, QF: quadriceps femoris; SD: standard deviation

Figure 3 shows that there was a moderate association between PhA and grip strength (men: r=0.567, p<0.001, women: r=0.554, P<0.001) and walking speed (men: r=0.415, p<0.001, women: r=0.445, P<0.001) (Figure 3A, B). Similarly, PhA was weakly associated with echo intensity (men: r=0.219, p<0.001, women: r=0.174, P<0.001) and muscle thickness of the quadriceps femoris muscle (for men: r=-0.368, p<0.001, for women: r=-0.249, P<0.001) (Figure 3C, D).

The ROC analysis enabled us to calculate the best cutoff of PhA (men: 4.05°, women: 3.55°) to discriminate sarcopenia from nonsarcopenia, and the AUCs of PhA in men and women were 0.718 (95% confidence interval (CI): 0.652-0.784) and 0.721 (95%CI: 0.669-0.773), respectively (Figure 4A, B). Similarly, the ROC analysis indicated the best cutoff for PhA (men: 4.05°, women: 3.55°) to discriminate sarcopenia and dynapenia from normal and presarcopenia, and the AUCs of PhA in men and women were 0.78 (95%CI: 0.725-0.831) and 0.788 (95%CI: 0.755-0.821), respectively (Figure 4C, D).

Figure 1
Comparison of PhA among 4 groups. A significant difference was observed among the four groups in both sexes (P<0.05). In men, the dynapenia and sarcopenia groups showed significantly lower measures of PhA than the normal group according to multivariate analysis (P<0.05) (A). In women, the dynapenia and sarcopenia groups showed significantly lower measures in PhA than the normal and presarcopenia groups according to multivariate analysis (P<0.05) (B)

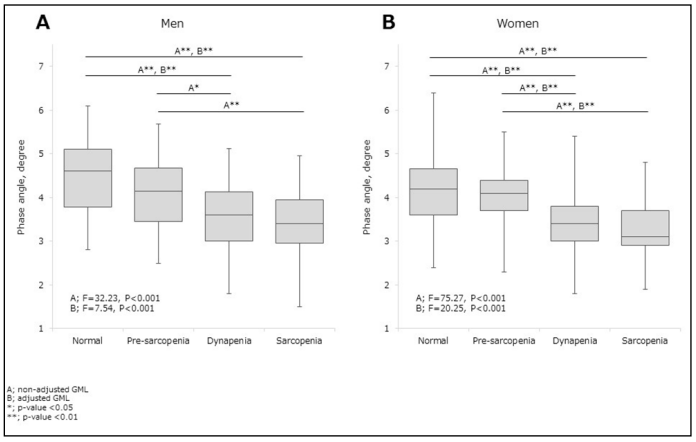


Figure 2
The relationship between PhA and sarcopenia classification. The proportion of sarcopenia and dynapenia was closely related to phase angle in men (A) and women (B)

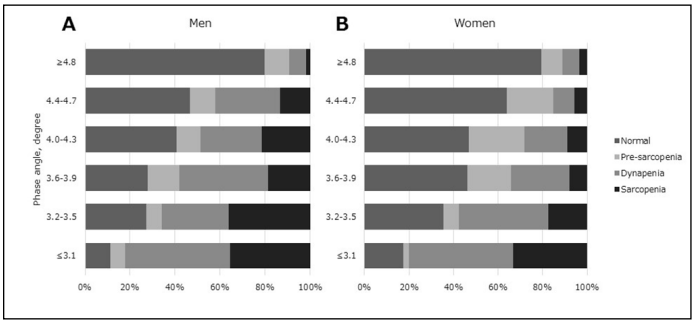


Figure 3
Association of PhA with grip strength and walking speed in men (A) and women (B). PhA was associated with muscle quality (echo intensity for quadriceps femoris) and muscle quantity (muscle thickness for quadriceps femoris) in men (C) and women (D)

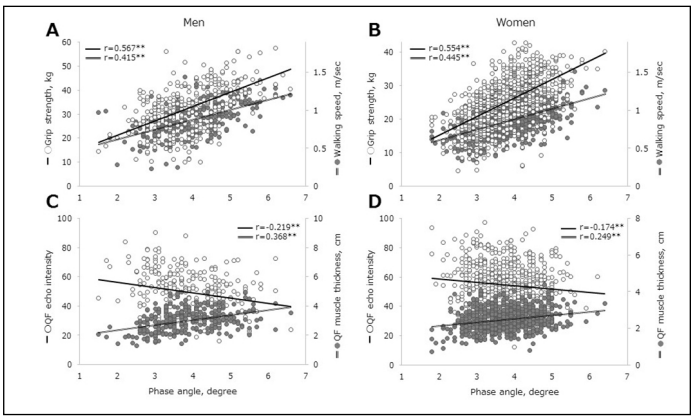
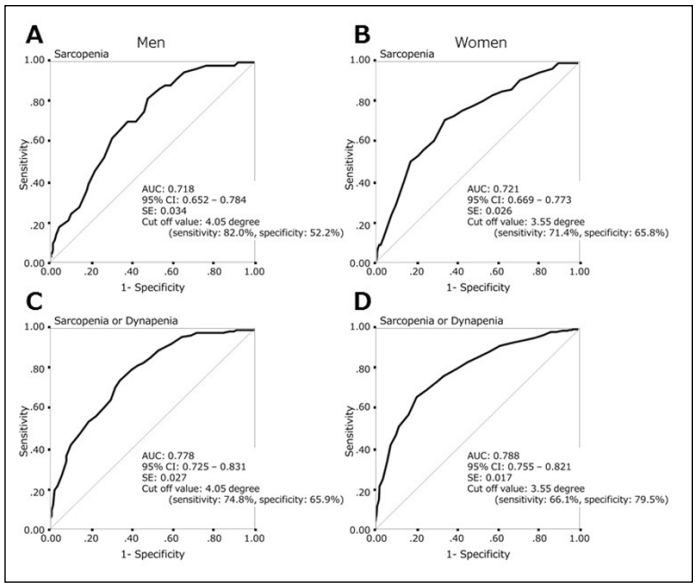


Figure 4
The ROC analysis indicated the best cutoff of PhA (men: 4.05° (A), women: 3.55° (B)) to discriminate sarcopenia from nonsarcopenia. Similarly, ROC analysis indicated the cutoff of PhA (men: 4.05° (C), women: 3.55° (D)) to discriminate sarcopenia and dynapenia from normal and presarcopenia



Discussion

This study found that dynapenic and sarcopenic older adults showed a lower PhA than normal older adults in both sexes. Importantly, there was no significant difference in PhA between dynapenia and sarcopenia because PhA was moderately correlated with physical performance, such as muscle strength and walking speed. In addition, the proportion of sarcopenia and dynapenia was increased according to the reduction of PhA. For these reasons, we could propose a cutoff value of PhA to discriminate sarcopenia and dynapenia from normal and presarcopenia (men: 4.05°, women: 3.55°).

PhA was lower in sarcopenic and dynapenic older adults than in normal and presarcopenic older adults and was moderately associated with physical performance in both sexes. These results were consistent with previous reports; some reports indicated that PhA is gradually decreased according to functional decline, such as lower muscle strength (4-6) and sarcopenia severity (5, 20). Thus, PhA may indicate the level of skeletal muscle function, and PhA may be a useful and robust indicator for sarcopenia and dynapenia.

The relationship between PhA and muscle functions is not completely understood, but there are some possibilities for this association. Higher PhA indicates better cell membrane structure, cell mass, cellular integrity, and cell function (1-3). One of our interesting findings was that PhA was associated with both muscle quantity and quality. A previous study also reported that PhA was correlated to muscle quantity, quality, and function (4-6, 23). Thus, a higher value of PhA may be a good indicator for both muscle quality and quantity. In addition, PhA is a sensitive marker for muscle strength and physical performance. It has been suggested that PhA may be modulated by short-term resistance training (23-25).

The AUCs were higher when sarcopenia and dynapenia were combined than for sarcopenia alone in both sexes. PhA shows almost the same value in sarcopenic and dynapenic older adults. In addition, our previous studies also indicated that several skeletal muscle characteristics and concentration of plasma essential amino acids show similar trends in sarcopenic and dynapenic older adults (18, 19). Based on these findings, we propose that sarcopenia and dynapenia are equally high-risk factors for physical impairment, and appropriate management should be provided for these pathological conditions.

Our cutoff value of PhA to detect sarcopenia was relatively low compared with that found in previous studies. The cutoff value of PhA for sarcopenia is 4.55° in a Turkish report (20), and the average PhA for sarcopenia is 5.6 and 5.8 in men and women, respectively, in a Brazilian study (5). These studies report higher PhA values than ours. There are two possible reasons to explain the difference: one is the kind of equipment used, and the other is the ethnicity of the study participants. In the Turkish and Brazilian studies, PhA was measured using the tab-type bioelectrical impedance data acquisition system (5, 20). On the other hand, in this study, PhA was calculated using a nontab-type bioelectrical impedance system: participants stood on two metallic electrodes and held metallic grip electrodes. Second, there is a relatively large difference in PhA according to race; for example, PhA is lower in Asian adults than in white, multiracial, African American, or other ethnic groups (27). Thus, Turkish and Brazilian PhA values tend to be higher than those of Asian populations, such as the Japanese.

The advantage of our findings is the following: this study has a relatively large sample size compared to previous reports, and the participants of this study are Asian people. As described previously, PhA values may differ by ethnic group. However, there are very few reports about PhA from Asian populations; thus, our data on the Japanese older population are important in this field.

There are several limitations of this study that warrant mention. First, these findings were provided by a cross-sectional design. Further research with a longitudinal design is required to clarify whether a lower PhA influences adverse health outcomes or incident sarcopenia and dynapenia. Second, PhA was calculated using a nontab-type bioelectrical impedance system. However, most of the previous studies use tab-type bioelectrical impedance systems to evaluate PhA. Therefore, it is necessary to carefully judge the difference. Third, muscle quantity and quality were assessed using ultrasonography. In fact, the lack of consensus for using this method is a serious disadvantage (27); thus, well-trained examiners performed all the measurements in this study.

These findings suggest that PhA is associated with muscle quantity and quality and may be a useful indicator for sarcopenia and dynapenia. In addition, we were able to determine the cutoff value of the PhA to discriminate sarcopenia and dynapenia from normal and presarcopenia (men: 4.05°, women: 3.55°) in community-dwelling Japanese older adults.

Acknowledgements: The authors acknowledge Mr. Buichi Tanaka, Ms. Tomomi Umezaki, Ms. Kumi Iwasaki, Mr. Yukiko Tachibana, and Ms. Atsuko Kawasaki for their contributions to the data collection. This work was supported by JSPS KAKENHI Grant Number 16H05921 and 17H04153.

Conflict of Interest: The authors have no potential conflicts of interest to disclose.

Ethical standards: The ethics committee approved the study.

References

1. De Lorenzo A, Andreoli A, Matthie J, et al. Predicting body cell mass with bioimpedance by using theoretical methods: a technological review. J Appl Physiol (1985) 1997; 82: 1542-1558.
2. Lukaski HC. Evolution of bioimpedance: a circuitous journey from estimation of physiological function to assessment of body composition and a return to clinical research. Eur J Clin Nutr 2013; 67: S2-S9.
3. Norman K, Stobäus N, Pirlich M, et al. Bioelectrical phase angle and impedance vector analysis--clinical relevance and applicability of impedance parameters. Clin Nutr 2012; 31: 854-861.
4. Basile C, Della-Morte D, Cacciatore F, et al. Phase angle as bioelectrical marker to identify elderly patients at risk of sarcopenia. Exp Gerontol 2014; 58: 43-46.
5. Santana NM, Pinho CPS, da Silva CP, et al. Phase Angle as a Sarcopenia Marker in Hospitalized Elderly Patients. Nutr Clin Pract 2018; 33: 232-237.
6. Yamada Y, Buehring B, Krueger D, et al. Electrical Properties Assessed by Bioelectrical Impedance Spectroscopy as Biomarkers of Age-related Loss of Skeletal Muscle Quantity and Quality. J Gerontol A Biol Sci Med Sci 2017; 72: 1180-1186.
7. Barbosa-Silva MC, Barros AJ, Wang J, et al. Bioelectrical impedance analysis: population reference values for phase angle by age and sex. Am J Clin Nutr 2005; 82: 49-52.
8. Stobäus N, Pirlich M, Valentini L, et al. Determinants of bioelectrical phase angle in disease. Br J Nutr 2012; 107: 1217-1220.
9. Fein PA, Gundumalla G, Jorden A, et al. Usefulness of bioelectrical impedance analysis in monitoring nutrition status and survival of peritoneal dialysis patients. Adv Perit Dial 2002; 18: 195-199.
10. Norman K, Wirth R, Neubauer M, et al. The bioimpedance phase angle predicts low muscle strength, impaired quality of life, and increased mortality in old patients with cancer. J Am Med Dir Assoc 2015; 16: 173.e17-22.
11. Wirth R, Volkert D, Rösler A, et al. Bioelectric impedance phase angle is associated with hospital mortality of geriatric patients. Arch Gerontol Geriatr 2010; 51: 290-294.
12. Wilhelm-Leen ER, Hall YN, Horwitz RI, et al. Phase angle, frailty and mortality in older adults. J Gen Intern Med 2014; 29: 147-154.
13. Beaudart C, Zaaria M, Pasleau F, et al. Health Outcomes of Sarcopenia: A Systematic Review and Meta-Analysis. PLoS One 2017; 12: e0169548.
14. Bianchi L, Ferrucci L, Cherubini A, et al. The Predictive Value of the EWGSOP Definition of Sarcopenia: Results From the InCHIANTI Study. J Gerontol A Biol Sci Med Sci 2016; 71: 259-264.
15. Visser M, Goodpaster BH, Kritchevsky SB, et al. Muscle mass, muscle strength, and muscle fat infiltration as predictors of incident mobility limitations in well-functioning older persons. J Gerontol A Biol Sci Med Sci 2005; 60: 324-333.
16. Newman AB, Kupelian V, Visser M, et al. Strength, but not muscle mass, is associated with mortality in the health, aging and body composition study cohort. J Gerontol A Biol Sci Med Sci 2006; 61: 72-77.
17. Cesari M, Pahor M, Lauretani F, et al. Skeletal muscle and mortality results from the InCHIANTI Study. J Gerontol A Biol Sci Med Sci 2009; 64: 377-384.
18. Yamada M, Kimura Y, Ishiyama D, et al. Differential characteristics of skeletal muscle in community-dwelling older adults. J Am Med Dir Assoc 2017; 18: 807. e9-807.e16.
19. Yamada M, Kimura Y, Ishiyama D, et al. Plasma amino acid concentrations are associated with muscle function in older Japanese women. J Nutr Health Aging 2018; 22: 819-823.
20. Kilic MK, Kizilarslanoglu MC, Arik G, et al. Association of Bioelectrical Impedance Analysis-Derived Phase Angle and Sarcopenia in Older Adults. Nutr Clin Pract 2017; 32: 103-109.
21. Chen LK, Liu LK, Woo J, et al. Sarcopenia in Asia: consensus report of the Asian Working Group for Sarcopenia. J Am Med Dir Assoc 2014; 15: 95-101.
22. Cruz-Jentoft AJ, Baeyens JP, Bauer JM, et al. Sarcopenia: European consensus on definition and diagnosis: Report of the European Working Group on Sarcopenia in Older People. Age Ageing 2010; 39: 412-423.
23. Cunha PM, Tomeleri CM, Nascimento MAD, et al. Improvement of cellular health indicators and muscle quality in older women with different resistance training volumes. J Sports Sci 2018; 23: 1-6.
24. Dos Santos L, Cyrino ES, Antunes M, et al. Changes in phase angle and body composition induced by resistance training in older women. Eur J Clin Nutr 2016; 70: 1408-1413.
25. Ribeiro AS, Schoenfeld BJ, Souza MF, et al. Resistance training prescription with different load-management methods improves phase angle in older women. Eur J Sport Sci 2017; 17: 913-921.
26. Barbosa-Silva MC, Barros AJ, Wang J, et al. Bioelectrical impedance analysis: population reference values for phase angle by age and sex. Am J Clin Nutr 2005; 82: 49-52.
27. Ticinesi A, Meschi T, Narici MV, et al. Muscle Ultrasound and Sarcopenia in Older Individuals: A Clinical Perspective. J Am Med Dir Assoc 2017; 18: 290-300.