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Simplified morphological evaluation of skeletal muscle mass and maximum muscle strength in healthy young women: Comparison between thigh and calf

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Abstract

Objectives: The purpose of this study was to examine the prediction of skeletal muscle mass and maximum muscle strength using simplified morphology evaluation in young Japanese women from the thigh and calf perspective.

Methods: A total of 249 Japanese young women (aged 18–25 years) were used for data analyses in this study. Thigh and calf girths were measured using a tape measure at 50% of thigh length and at 30% proximal of calf length, respectively. Muscle thickness was measured using B-mode ultrasound at the anterior and posterior thigh (at 50% of thigh length) and at the posterior lower leg (at 30% proximal of calf length), respectively. The measurements were carried out on the right side of the body while the participants stood with their elbows extended and relaxed. A stepwise multiple regression analysis (method of increasing and decreasing the variables; criterion set at $p < 0.05$) was performed for skeletal muscle index (defined by appendicular skeletal muscle mass/height^2), handgrip strength, or sit-to-stand test and five variable factors (girth (thigh and calf) and muscle thickness (anterior and posterior thigh and posterior calf)).

Results: Unlike the sit-to-stand test, skeletal muscle index or handgrip strength was correlated ($p < 0.001$) with the girth or muscle thickness for both thigh and calf. Unlike the sit-to-stand test, the prediction equations for skeletal muscle index and handgrip strength estimation showed significant correlations with multiple regression analysis of data obtained from the calf girth and muscle thickness. In both skeletal muscle index and handgrip strength, calf girth was adopted as a Step 1, respectively.

Conclusion: Our results indicated that skeletal muscle index and handgrip strength could be evaluated by the simplified morphology methods, especially that for the calf girth measurement, which may be a good indicator of screening/preventing for sarcopenia in healthy Japanese young women.

Keywords

circumference, Japanese university fresh women, lower leg, sarcopenia, skeletal muscle index, upper leg

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Introduction

Loss of skeletal muscle mass, sarcopenia, is associated with serious problems (i.e. falls, fractures, disability, and heart disease),[1–3] and it is also associated with increased healthcare costs.[4] Therefore, the European Working Group on Sarcopenia in Older People (EWGSOP) and the Asian Working Group for Sarcopenia (AWGS) introduced the most widely used consensus, which recommends cut-offs of skeletal muscle index (SMI, defined by appendicular skeletal muscle mass/height^2), muscle strength (handgrip), and physical capability (sit-to-stand, etc.) for diagnosing and assessing sarcopenia.[5,6] Notably, a previous study

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reported that, among young adults, the prevalence of sarcopenia is higher in women than in men.[7] In addition, a recent study revealed that the ratio of "presarcopenia" (low SMI without impact on muscle strength or physical capability) was approximately 36% for healthy young women in Japan.[8] This means that the sarcopenia assessment is particularly attentive for the healthy young women in early prevention of mobility problems and frailty.

There are some methods typically used to evaluate skeletal muscle mass, including quantitative techniques such as dual-energy X-ray absorptiometry (DXA) and bioelectrical impedance analyzer (BIA) methods. Although the SMI assessed by the DXA and the BIA methods is used widely to diagnose sarcopenia,[9–13] these methods are limited to research and clinical practice due to their high cost and lack of portability. The DXA in particular is not portable and may even be dangerous due to radiation exposure. Moreover, the precision of BIA in measuring muscle mass is controversial, because the SMI values differ substantially depending on the type of BIA device.[14,15] Therefore, these methods are not practical in large field–based studies or epidemiologic studies and thus, there is a need for a simple, inexpensive, and field-based method for measuring SMI. In addition, previous study reported that severely impaired mobility patients (for cardiovascular disease inpatients) failed to perform the sit-to-stand test (13.5% for male and 17.3% for female, respectively).[3] Therefore, simplified morphology methods are useful tools for evaluating sarcopenia diagnosis regardless of physical health condition.

There are some studies concerning sarcopenia using simplified morphology evaluation (muscle thickness and girth, etc.). For example, some studies have demonstrated that thigh muscle morphology (muscle thickness) was a major contributing factor to sarcopenia in older adults and patients.[3,16,17] However, recent studies suggested that calf muscle morphology (girth) could be used as a good indicator of muscle mass for diagnosing sarcopenia in middle-aged and elderly.[18,19] Taken together, it is unclear the important combination of site (thigh and/or calf) and measurement (muscle thickness (MTH) and/or girth) for preventing the sarcopenia (muscle mass, strength, and physical capability) from a young age. In addition, some studies reported that muscle morphology (thigh girth or MTH) was significantly correlated with muscle strength (handgrip or knee extension) and skeletal muscle mass (lean body mass) in young/middle-aged adults.[20–22] Therefore, we hypothesized that thigh muscle morphology rather than calf muscle morphology would be a useful indicator in evaluating skeletal muscle mass and maximum muscle strength. The purpose of this study was to examine the prediction of skeletal muscle mass and maximum muscle strength using simplified morphology evaluation in young Japanese women from the thigh and calf perspective.

Methods

Participants

A total of 250 Japanese university freshmen women (aged 18–25 years) were recruited through oral communications in a "Sports Practice" course in our university. Before informed consent was obtained, a written description of the purpose of the study and its safety was distributed to potential subjects, along with a lifestyle questionnaire. All subjects were free of overt chronic disease (e.g. diabetes, angina, myocardial infarction, cancer, and stroke) as assessed by medical examination report. However, a participant ($n = 1$) with musculoskeletal disease and knee joint surgery was excluded in this study. As a result, 249 university freshmen women were used for data analyses. The participants in this study were classified as "recreationally active"; 57 of 249 participated in regular aerobic-type exercise (walking, jogging, or cycling; two to three times per week for approximately 30 min). None of the participants had participated in strength/resistance-type training for 6 months before the start of the study. The study was conducted according to the Declaration of Helsinki and was approved by the university's Ethics Committee for Human Experiments. Written informed consent was obtained from all the participants.

Body mass index, percent body fat, and SMI

Body mass and standing height were measured to the nearest 0.1 kg and 0.1 cm, respectively, using a height scale and an electronic weight scale. Body mass index (BMI) was defined as body mass/height^2 (kg/m^2). The multi-frequency BIA, InBody 430 analyzer (Biospace Co., Ltd, Seoul, Korea) was used according to the manufacturer's guidelines. BIA is used to estimate the body composition according to the difference of conductivity of the various tissues based on the differences in their biological characteristics. This body composition analyzer adopts a tetrapolar, eight-point tactile electrode system that separately measures impedance of the arms, trunk, and legs at three different frequencies (5, 50, and 250 kHz) for each segment.[23–25] The measurements were carried out while the subjects rested quietly in the supine position, with their elbows extended and relaxed along their trunk. The InBody automatically estimates weight, BMI, percent body fat, and lean soft tissue of the two upper limbs and two lower limbs. SMI (appendicular muscle mass (AMM)/height^2, kg/m^2) was calculated as the sum of the two upper limbs and two lower limbs.

MTH and girth

After thigh and calf length measurements using anatomic landmarks, all measurement sites were marked with a marker pen and then thigh, at 50% between the lateral condyle of the femur and the greater trochanter, and calf, at 30% proximal between the lateral malleolus of the fibula and the lateral condyle of the tibia, girths were measured using a tape measure on the right side of the body.[8,20] Ultrasound evaluation of MTH was performed using a real-time linear electronic scanner with a 10.0-MHz scanning head (5.5 cm length probe, ProSound C3CV, Hitachi Aloka System, Tokyo, Japan). The scanning head was coated with a water-soluble transmission gel to provide acoustic contact without depressing the dermal surface. The subcutaneous adipose tissue–muscle interface and the muscle–bone interface were identified from the ultrasonic image. The perpendicular distance from the adipose tissue–muscle interface to the muscle–bone interface was considered to represent MTH. Briefly, the measurements were carried out on the right side of the body while the participants stood with their elbows extended and relaxed.[8,20] Two images from the same site were stored, and the mean value was used for data analysis. The coefficient of variance (CV) of MTH measurement from test to retest was 1.3%. The same investigator made all of the ultrasound measurements.

Table 1. The physical characteristics and clinical data in Japanese university women.

Variable	Mean (SD)	Range
Age, years	18.3 (0.8)	18–25
Standing height, cm	157.1 (5.4)	144.0–171.5
Body weight, kg	51.2 (7.9)	35.0–89.5
BMI, kg/m^2	20.7 (2.8)	15.2–37.0
Percent body fat	26.2 (5.9)	12.9–48.4
Fat mass, kg	13.8 (5.1)	5.1–43.4
Morphological assessment		
SMI, kg/m^2	5.97 (0.54)	4.61–7.85
Thigh girth, cm	48.9 (4.3)	39.4–69.0
Calf girth, cm	34.5 (2.7)	28.6–43.7
Anterior thigh MTH, cm	4.60 (0.56)	3.42–6.61
Posterior thigh MTH, cm	5.40 (0.49)	3.91–6.87
Calf MTH, cm	6.03 (0.51)	4.46–7.47
Functional assessment		
Handgrip, kg	26.4 (3.7)	15.7–36.5
Sit-to-stand test, reps/30 s	32.8 (5.6)	10–46

SD: standard deviation; BMI: body mass index; SMI: skeletal muscle mass index; MTH: muscle thickness.
Data are given as mean (standard deviation).

Handgrip strength

Handgrip strength was measured using a factory-calibrated hand dynamometer (TKK 5401, Takei, Tokyo, Japan). All subjects were instructed to maintain an upright standing position, arms at their side, holding the dynamometer in the right hand with the elbow extended at 180° without squeezing their arm against their body. The size of the dynamometer handle was set so that it felt comfortable to the subject while squeezing the grip. Each subject underwent two trials, and the best value of the trials was used for analysis.

Sit-to-stand test

A wooden molded chair (0.40 m height and 0.30 m depth) was used for the sit-to-stand test. The subjects were asked to stand up from a sitting position and then to sit down during 30 s as many times as possible. The subjects were instructed to stand up fully and to place their buttocks on the chair in a sitting position between repetitions.[26] The test started when the examiner said "Go" and stopped after 30 s.[27] Prior to the measurements, practice trials with submaximal effort were performed for positioning and learning of the task. Each subject performed two trials with an interval of at least 3 min between trials. The highest repetition score was adopted for the individual data.

Statistical analyses

Results are expressed as mean ± standard deviation for all variables. All data were analyzed using JMP v.12.0 for Mac (SAS Institute Inc., Tokyo, Japan). Pearson product correlations of SMI, handgrip strength, and sit-to-stand test and variable factors were also statistically quantified. Receiver operating characteristic (ROC) curves were plotted to identify an optimal lower body girth or MTH cut-off for detecting presarcopenia (SMI <5.7 kg/m^2). Since the value of events per variable = 10 seems most prudent for regression analysis,[28] five variable factors were acceptably for women ($n=249$). In addition, the variance inflation factor (VIF) was used to determine the degree of multi-collinearity of the ith independent variable with other independent variables for all hierarchal regression models.[17] Multi-collinearity between variables was defined as a VIF $\geqslant 10$. Based on the result of VIF, a stepwise multiple regression analysis (method of increasing and decreasing the variables, criterion was set at $p<0.05$) was performed to SMI, handgrip strength, or sit-to-stand test and five variable factors (girth (mid-thigh and lower-leg) and MTH (anterior and posterior mid-thigh and posterior lower-leg)). Consequently, the predicted variables, coefficients, and intercept coefficients were automatically picked out by the JMP software. Statistical significance was set at $p<0.05$.

Results

The physical characteristics and clinical data are listed in Table 1. The correlation coefficients between SMI, handgrip strength, or sit-to-stand test and girth or MTH are shown in Table 2. Unlike the sit-to-stand test, SMI or handgrip strength was correlated ($p<0.001$) with the girth or MTH for both thigh and calf (Table 2). In thigh

Table 2. Pearson's correlation coefficients between skeletal muscle index (SMI), handgrip strength, or sit-to-stand test and girth or muscle thickness in Japanese young women.

	Girth		MTH		
	Thigh	Calf	Anterior thigh	Posterior thigh	Posterior calf
SMI	0.801*	0.805*	0.582*	0.546*	0.666*
Handgrip strength	0.339*	0.377*	0.323*	0.341*	0.322*
Sit-to-stand test	−0.058	−0.062	0.055	−0.063	−0.061

SMI: skeletal muscle mass index; MTH: muscle thickness.
*$p < 0.001$.

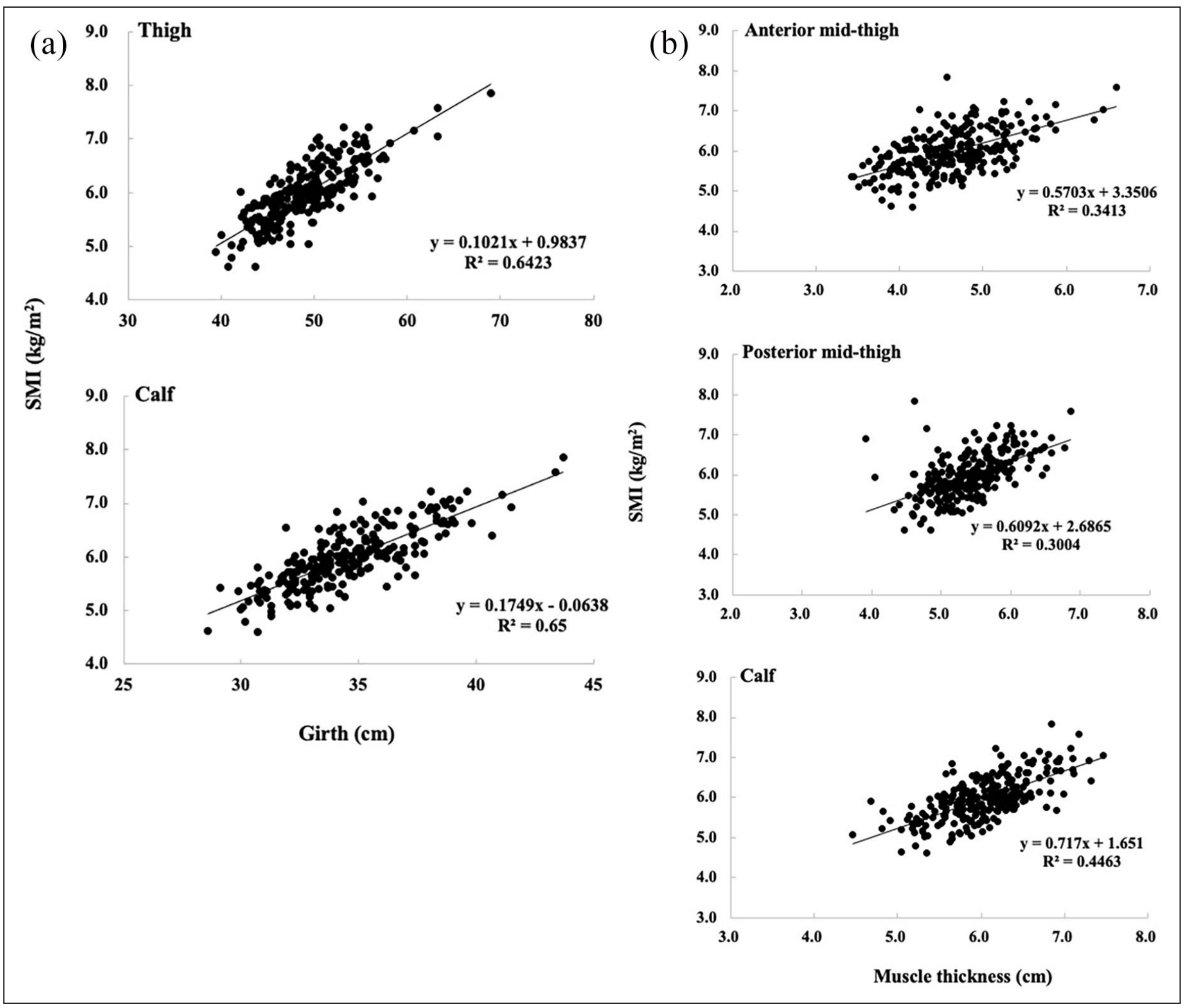

Figure 1. Relationships between girth (a) or muscle thickness (b) and skeletal muscle index (SMI) of Japanese young women.

and calf, there was an excellent relationship between girth and SMI ($p < 0.001$) (Figure 1). ROC curves were plotted to identify the optimal girth or MTH cut-offs for detecting presarcopenia. The area under the curve (AUC) and the sensitivity were high values for both the girth (89.0%–90.3% for AUC and 81.1%–82.3% for sensitivity) and the MTH (77.3%–82.9% for AUC and 75.7%–86.5% for sensitivity) to detect presarcopenia. In contrast, the specificity was lower values with the MTH (41.0%–48.7%) than the girth (66.1%–67.7%) (Table 3). Unlike the sit-to-stand test, the prediction equations for SMI and handgrip strength estimation showed significant correlations with multiple regression analysis of data obtained from the calf girth and MTH (Table 4). In both SMI and handgrip strength, calf girth was adopted as a Step 1, respectively.

Table 3. Optimal cut-off values of girth and MTH in lower extremities for diagnosing presarcopenia (SMI <5.7 kg/m^2) in Japanese university women.

Variable	Cut-off value (cm)	*p*-value	AUC	Sensitivity	Specificity
Girth					
Thigh	46.8	<0.001	0.903	0.823	0.677
Calf	33.3	<0.001	0.890	0.811	0.661
MTH					
Anterior thigh	4.53	<0.001	0.773	0.757	0.410
Posterior thigh	5.45	<0.001	0.782	0.865	0.455
Calf	6.02	<0.001	0.829	0.851	0.487

MTH: muscle thickness; SMI: skeletal muscle index; AUC: area under the curve.

Table 4. Prediction equations for SMI, handgrip strength, or sit-to-stand test estimation based on multiple regression analysis of data obtained from girth and MTH in lower extremities.

	Prediction equations (kg)	R^2	RMSE	*p*-value
SMI				
Step 1	SMI (kg/m^2) = 0.175 × calf girth (cm) − 0.064	0.650	0.32	<0.001
Step 2	SMI (kg/m^2) = 0.097 × calf girth (cm) − 0.052 × thigh girth (cm) + 0.115	0.684	0.31	<0.001
Handgrip strength				
Step 1	Handgrip (kg) = 0.567 × calf girth (cm) + 6.790	0.144	3.46	<0.001
Step 2	Handgrip (kg) = 0.419 × calf girth (cm) + 1.669 × posterior calf MTH (cm) + 2.861	0.181	3.39	<0.001
Step 3	Handgrip (kg) = 0.316 × calf girth (cm) + 1.480 × posterior calf MTH (cm) + 0.929 × anterior thigh MTH (cm) + 3.192	0.194	3.36	0.047
Sit-to-stand test				
Step 1	–	–	–	–

SMI: skeletal muscle index; MTH: muscle thickness; RMSE: root-mean-square error.

Discussion

The main findings of this study were as follows: first, the muscle morphology for both thigh and calf was found to be an effective tool for the prediction of SMI and handgrip strength in healthy young women. Second, SMI was strongly correlated with girth, which was comparable with MTH for both thigh and calf.

The standing height, body mass, and percent body fat in this study (157 cm, 51.2 kg, and 26.2%) was nearly the same as in the previous study (158 cm, 52.0 kg, and 24.3% (n=207, 20–39 years)).[17] In addition, the values and the CVs of the morphological assessment and the functional assessment in this study were nearly the same as in the previous studies (thigh girth, 48.9 ± 4.3 cm and 8.7% vs 48.5 ± 3.4 cm and 7.0%; calf girth, 34.5 ± 2.7 cm and 7.8% vs 34.8 ± 2.1 cm and 6.0%; anterior thigh MTH, 4.60 ± 0.56 cm and 12.2% vs 4.68 ± 0.59 cm and 12.6%; posterior thigh MTH, 5.40 ± 0.49 cm and 9.1% vs 5.19 ± 0.55 cm and 10.6%; calf MTH, 6.03 ± 0.51 cm and 8.5% vs 6.06 ± 0.49 cm and 8.1%; handgrip, 26.4 ± 3.7 cm and 14.0% vs 25.3 ± 6.6 cm and 26.1%; 30 s sit-to-stand test, 32.8 ± 5.6 reps and 17.1% vs 27.0 ± 5.7 reps and 21.0%).[29–32] Thus, it appears that the body composition and somatotype characteristics in this study demonstrate the present situation as a general population of healthy Japanese young women.

Previously, thigh muscle morphology was a major contributing factor to sarcopenia in older adults,[8,16,17] but calf muscle morphology could be used as a good indicator of muscle mass for diagnosing sarcopenia in middle-aged and elderly.[18,19] In this study, the prediction equations (Steps 1 and 2 for SMI and Steps 1–3 for handgrip strength) was particularly high contributed from the calf morphology. Previous study indicates that thigh girth might help general practitioners in early identification of individuals at an increased risk of premature morbidity and mortality in both men and women.[33] However, calf girth measurement may be easier to perform everywhere for young women, like unique simplified method as represented by "Yubi-Wakka (finger-ring)" test.[34] Moreover, in this study, the <33.3 cm for calf girth was calculated by cut-offs for diagnosing presarcopenia (Table 3). This result was exactly similar to that of a previously reported study on AWGS 2019 (<33 cm for women for screening or case finding).[6] Furthermore, the specificity was high values with the girth compared with the MTH for lower extremities (Table 3). Taken together, calf measurement, and in particular that based on girth measurement, is a good indicator of SMI associated with sarcopenia diagnosis from young women.

Previous study recommend that handgrip strength is the most useful tool of age-related change in muscle strength in older adults,[35] because this strength is correlated with lower extremity muscle strength.[36,37] In addition, EWGSOP-2 recommend that sit-to-stand test (also called chair stand test and chair rise test) can be used as a proxy for strength of muscles (quadriceps muscles).[6] In this study, our results suggest that thigh and calf muscle morphology may be a useful parameter for evaluating handgrip strength, but not for sit-to-stand test, in young Japanese women. In general, muscle size (morphology) is a major determinant of muscle strength,[38,39] suggesting that handgrip strength was correlated with lower extremity (thigh and calf) muscle morphology. However, since the chair stand test requires both strength and endurance,[35] it appears that sit-to-stand test did not have a significant correlation with thigh and calf muscle morphology.

The limitation of this study should be discussed. As the subjects were Japanese young women, the ethnic group, the age distribution, and the physical characteristics were very limited. Additional research is needed to address this issue.

In conclusion, this study indicated that SMI and handgrip strength could be evaluated by the simplified morphology methods, especially that for the calf girth measurement, which may be a good indicator of screening/preventing for sarcopenia in healthy Japanese young women.

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Declaration of conflicting interests

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References

1. Haykowsky MJ, Brubaker PH, Morgan TM, et al. Impaired aerobic capacity and physical functional performance in older heart failure patients with preserved ejection fraction: role of lean body mass. *J Gerontol A Biol Sci Med Sci* 2013; 68(8): 968–975.
2. 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(3): 324–333.
3. Yasuda T, Nakajima T, Sawaguchi T, et al. Short physical performance battery for cardiovascular disease inpatients: implications for critical factors and sarcopenia. *Sci Rep* 2017; 7(1): 17425.
4. Janssen I, Shepard DS, Katzmarzyk PT, et al. The healthcare costs of sarcopenia in the United States. *J Am Geriatr Soc* 2004; 52(1): 80–85.
5. Chen LK, Woo J, Assantachai P, et al. Asian Working Group for sarcopenia: 2019 consensus update on sarcopenia diagnosis and treatment. *J Am Med Dir Assoc* 2020; 21(3): 300–307.
6. Cruz-Jentoft AJ, Bahat G, Bauer J, et al. Sarcopenia: revised European consensus on definition and diagnosis. *Age Ageing* 2019; 48(4): 601.
7. Yamada M, Nishiguchi S, Fukutani N, et al. Prevalence of sarcopenia in community-dwelling Japanese older adults. *J Am Med Dir Assoc* 2013; 14(12): 911–915.
8. Yasuda T. Anthropometric, body composition and somatotype characteristics of Japanese young women: implications for normal-weight obesity syndrome and sarcopenia diagnosis criteria. *Interv Med Appl Sci* 2019; 11(2): 117–121.
9. Baumgartner RN, Koehler KM, Gallagher D, et al. Epidemiology of sarcopenia among the elderly in New Mexico. *Am J Epidemiol* 1998; 147(8): 755–763.
10. Kim YS, Lee Y, Chung YS, et al. Prevalence of sarcopenia and sarcopenic obesity in the Korean population based on the Fourth Korean National Health and Nutritional Examination Surveys. *J Gerontol A Biol Sci Med Sci* 2012; 67(10): 1107–1113.
11. Lee WJ, Liu LK, Peng LN, et al. Comparisons of sarcopenia defined by IWGS and EWGSOP criteria among older people: results from the I-Lan longitudinal aging study. *J Am Med Dir Assoc* 2013; 14(7): 528.e1–7.
12. Pongchaiyakul C, Limpawattana P, Kotruchin P, et al. Prevalence of sarcopenia and associated factors among Thai population. *J Bone Miner Metab* 2013; 31(3): 346–350.
13. Sanada K, Miyachi M, Tanimoto M, et al. A cross-sectional study of sarcopenia in Japanese men and women: reference values and association with cardiovascular risk factors. *Eur J Appl Physiol* 2010; 110(1): 57–65.
14. Léger LA and Lambert J. A maximal multistage 20-m shuttle run test to predict VO2 max. *Eur J Appl Physiol Occup Physiol* 1982; 49(1): 1–12.
15. Yamada M, Yamada Y and Arai H. Comparability of two representative devices for bioelectrical impedance data acquisition. *Geriatr Gerontol Int* 2016; 16(9): 1087–1088.
16. Miyatani M, Kanehisa H, Azuma K, et al. Site-related differences in muscle loss with aging "a cross-sectional survey on the muscle thickness in Japanese men aged 20 to 79 years." *Int J Sport Health Sci* 2003; 1(1): 34–40.
17. Abe T, Sakamaki M, Yasuda T, et al. Age-related, site-specific muscle loss in 1507 Japanese men and women aged 20 to 95 years. *J Sports Sci Med* 2011; 10(1): 145–150.
18. Kawakami R, Murakami H, Sanada K, et al. Calf circumference as a surrogate marker of muscle mass for diagnosing sarcopenia in Japanese men and women. *Geriatr Gerontol Int* 2015; 15(8): 969–976.

19. Kim S, Kim M, Lee Y, et al. Calf circumference as a simple screening marker for diagnosing sarcopenia in older Korean Adults: the Korean Frailty and Aging Cohort Study (KFACS). *J Korean Med Sci* 2018; 33(20): e151.
20. Abe T, Kondo M, Kawakami Y, et al. Prediction equations for body composition of Japanese adults by B-mode ultrasound. *Am J Hum Biol* 1994; 6(2): 161–170.
21. Yasuda T. Field-based simplified approach of evaluating knee extensor muscle strength and size in university freshmen women. *J Sport Rehabil* 2019; 28(5): 398–401.
22. Yasuda T and Ichikawa D. Field-based simplified approach of evaluating knee extensor muscle strength and size in male university freshmen. *J Sports Sci* 2016; 4(5): 272–278.
23. Ishii S, Tanaka T, Shibasaki K, et al. Development of a simple screening test for sarcopenia in older adults. *Geriatr Gerontol Int* 2014; 14(Suppl. 1): 93–101.
24. Seino S, Shinkai S, Iijima K, et al. Reference values and age differences in body composition of community-dwelling older Japanese men and women: a pooled analysis of four cohort studies. *PLoS ONE* 2015; 10(7): e0131975.
25. Tagliabue A, Andreoli A, Comelli M, et al. Prediction of lean body mass from multifrequency segmental impedance: influence of adiposity. *Acta Diabetol* 2001; 38(2): 93–97.
26. Kanehisa H and Fukunaga T. Age-related change in sit-to-stand power in Japanese women aged 50 years or older. *J Physiol Anthropol* 2014; 16(33): 26.
27. Jones CJ, Rikli RE and Beam WC. A 30-s chair-stand test as a measure of lower body strength in community-residing older adults. *Res Q Exerc Sport* 1999; 70(2): 113–119.
28. Peduzzi P, Concato J, Feinstein AR, et al. Importance of events per independent variable in proportional hazards regression analysis. II. Accuracy and precision of regression estimates. *J Clin Epidemiol* 1995; 48(12): 1503–1510.
29. Miyatani M, Azuma K, Kanehisa H, et al. Site and gender differences in the age-related changes of muscle thickness in lower limbs—a comparison between the two generations of 20’s and 70’s. *Jpn J Phys Fit Sport Med* 2002; 52(Suppl.): 133–140.
30. Abe T, Loenneke JP, Thiebaud RS, et al. Age-related site-specific muscle wasting of upper and lower extremities and trunk in Japanese men and women. *Age* 2014; 36(2): 813–821.
31. Abe T, Counts BR, Barnett BE, et al. Associations between handgrip strength and ultrasound-measured muscle thickness of the hand and forearm in young men and women. *Ultrasound Med Biol* 2015; 41(8): 2125–2130.
32. Suetta C, Haddock B, Alcazar J, et al. The Copenhagen Sarcopenia Study: lean mass, strength, power, and physical function in a Danish cohort aged 20–93 years. *J Cachexia Sarcopenia Muscle* 2019; 10(6): 1316–1329.
33. Heitmann BL, Frederiksen P. Thigh circumference and risk of heart disease and premature death: prospective cohort study. *BMJ* 2009; 339: b3292.
34. Tanaka T, Takahashi K, Akishita M, et al. “Yubi-wakka” (finger-ring) test: a practical self-screening method for sarcopenia, and a predictor of disability and mortality among Japanese community-dwelling older adults. *Geriatr Gerontol Int* 2018; 18(2): 224–232.
35. 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(4): 412–423.
36. Lauretani F, Russo C, Bandinelli S, et al. Age-associated changes in skeletal muscles and their effect on mobility: an operational diagnosis of sarcopenia. *J Appl Physiol* 2003; 95(5): 1851–1860.
37. Taaffe DR, Cauley JA, Danielson M, et al. Race and sex effects on the association between muscle strength, soft tissue, and bone mineral density in healthy elderly: the Health, Aging, and Body Composition Study. *J Bone Miner Res* 2001; 16(7): 1343–1352.
38. Fukunaga T, Miyatani M, Tachi M, et al. Muscle volume is a major determinant of joint torque in humans. *Acta Physiol Scand* 2001; 172(4): 249–255.
39. Ikai M and Fukunaga T. A study on training effect on strength per unit cross-sectional area of muscle by means of ultrasonic measurement. *Int Z Angew Physiol* 1970; 28(3): 173–180.