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ORIGINAL ARTICLE

Effects of knee extensor muscle strength on the incidence of osteopenia and osteoporosis after 6 years

Yasumoto Matsui · Marie Takemura ·
Atsushi Harada · Fujiko Ando · Hiroshi Shimokata

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Abstract The association of knee extensor muscle strength with bone mineral density (BMD) has been reported in cross-sectional epidemiological studies, but it remains unclear whether or not this is the case with longitudinal change. Thus, we investigated whether or not the knee extension strength can predict the incidence of osteopenia or osteoporosis after 6 years, then compared the difference between sexes. Subjects were 1255 community-dwelling Japanese men and menopaused women, aged 40–81 years. BMD of lumbar spine and femoral neck was assessed by dual-energy X-ray absorptiometry twice at 6-year intervals. Subjects were divided into three groups, normal, osteopenia, and osteoporosis, depending on their young adult mean BMD % value. In the cross-sectional analysis the correlations between the knee extension strength and BMD of the two regions were examined, using Pearson's correlation coefficient. Longitudinal analyses were then conducted to determine the odds ratio, controlled for age and BMI, given that those who were normal in the initial stage developed osteopenia or osteoporosis after 6 years, for every 1 SD decrease in knee extension strength, as well as those who first had normal or osteopenia and then developed osteoporosis. Cross-sectional analysis showed a statistically significant relation between knee extensor muscle strength and BMD at both the lumbar spine ($p = 0.02$) and the femoral neck ($p < 0.0001$) only in men. The longitudinal analysis showed the significant effect of muscle strength on the loss of femoral neck BMD from normal to osteopenia or osteoporosis both in men (OR 1.84, 95 % CI 1.36–2.48, $p < 0.0001$) and in women (OR 1.29, 95 % CI 1.002–1.65, $p < 0.05$), as well as on the loss of spinal BMD from normal or osteopenia to osteoporosis only in men (OR 2.97, 95 % CI 1.07–8.23, $p < 0.05$). The results suggest the importance of knee extension strength to maintain the bone health of the proximal femur and spine in aging particularly in men.

Keywords Longitudinal epidemiological study · Knee extensor strength · Bone mineral density · Femoral neck · Lumbar spine

Introduction

Bone mineral density (BMD) is the greatest determinant of bone strength [1], so the loss of bone mass leads to the increased risk of fracture at that site. Several factors are known to affect the BMD or future bone loss, such as body weight [2, 3], age [2], nutrition [4], smoking [5, 6], physical exercise [7–11], physical training [12] or physical activity [6, 13, 14] and body composition like muscle mass [14–20]. Muscle strength is also known to associate with BMD [2, 6, 12, 13, 18, 19, 21–29]. Their association seems to be site-specific [26, 27] as well as systemic [13]. However, not many epidemiological studies have been carried out on a large scale regarding the influence of leg

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Y. Matsui (✉) · M. Takemura · A. Harada
Department of Orthopedic Surgery, National Center for Geriatrics and Gerontology, 35 Gengo, Morioka-cho, Obu, Aichi 474-8511, Japan
e-mail: matsui@ncgg.go.jp

F. Ando
Department of Health and Medical Sciences, Aichi Shukutoku University, Nagakute, Japan

H. Shimokata
Department for Development of Preventive Medicine, Center for Development of Advanced Medicine for Dementia, National Center for Geriatrics and Gerontology, Obu, Japan

strength on the longitudinal BMD changes; particularly those investigating the gender difference are rare. The purpose of our study is to clarify whether or not the knee extension strength can predict the incidence of osteopenia or osteoporosis after 6 years in the two regions of lumbar spine and femoral neck, and to compare the difference in sexes, utilizing a large cohort of local inhabitants.

Materials and methods

Subjects

The subjects were selected among people who participated in both the 2nd and 5th waves of the National Institute for Longevity Sciences Longitudinal Study of Aging (NILS-LSA). Details of the NILS-LSA are described elsewhere [30], but a brief description follows. This biannual examination to check the physical and mental condition so as to clarify the aging mechanism of ordinary Japanese people is conducted by the National Center for Geriatrics and Gerontology (NCGG), located in central Japan. The NILS is a research section of NCGG. The participants are chosen randomly among residents of Obu City and Higashiura-cho, in Aichi Prefecture in Japan.

For this study, data were analyzed from 763 men (57.3 ± 10.2, mean ± SD) and 476 women (62.0 ± 8.3, mean ± SD). In order to avoid the effect of menopause, we excluded the premenopausal women in the 2nd stage. Their age ranged from 40 to 81 (from 40 to 81 for men, and 41 to 80 years for women) at initial time (2nd wave). The 2nd and 5th waves were from April 2000 to May 2002, and July 2006 to July 2008, respectively, so the interval between the 2nd and 5th waves was 6 years. The number of participants who had a BMD examination in the 2nd wave were 1101 men and 732 women. So the response rates were 69.3 % (763 out of 1101) in men, and 65.0 % (476 out of 732) in women.

The reasons for non-response were various; such as moving out, health related problems, becoming the residents in the nursing homes, death, etc.

Measurements of bone mineral density

Bone mineral densities were measured using Hologic QDR4500, both at the initial time and after 6 years. Mean follow-up interval was 6.24 years ± 0.33. Data on the lumbar spine (L2–4) and the right side of the femoral neck were used for the analysis. For the state of bone density in terms of osteoporotic conditions, we adopted the classification widely used in Japan, as recommended by the Japanese Society for Bone and Mineral Research. Those who had equal or more than 80 % young adult mean (the YAM value of BMD), between 20 and 40-year-old, were classified as "normal," those who had equal or more than 70 and less than 80 % YAM as "osteopenia," and those with less than 70 % YAM as "osteoporosis." In the 2nd wave, numbers of subjects classified as normal, osteopenia and osteoporosis in lumbar spine were 633, 98, and 30, respectively, in men and 280, 134, and 78, respectively, in women, while in the 5th wave those classified as normal, osteopenia and osteoporosis in lumbar spine were 591, 121, and 51 in men, and 226, 176, and 90 in women, respectively. As for the femoral neck lesion, numbers of subjects classified as normal, osteopenia and osteoporosis in the 2nd wave were 680, 69, and 14, respectively, in men, and 352, 106, and 34, respectively, in women, while in the 5th wave those classified as normal, osteopenia and osteoporosis were 591, 121, and 51 in men, and 226, 176, and 90 in women, respectively.

Measurements of knee extension strength

Isometric knee extension strength was measured in the upright sitting position with knee and hip flexed 90°, as is often adopted in the usual epidemiological studies [31]. For more accuracy than by a handheld-dynamometer, we used a measurement device (Fig. 1) built by Takei Kiki Co., Niigata, Japan. This company has the responsibility for the verification and maintenance of this device every year. Measurements of knee extension strength were repeated three times, and the maximum values were used. Values measured for the right knee at the initial time wave were used for the analysis.

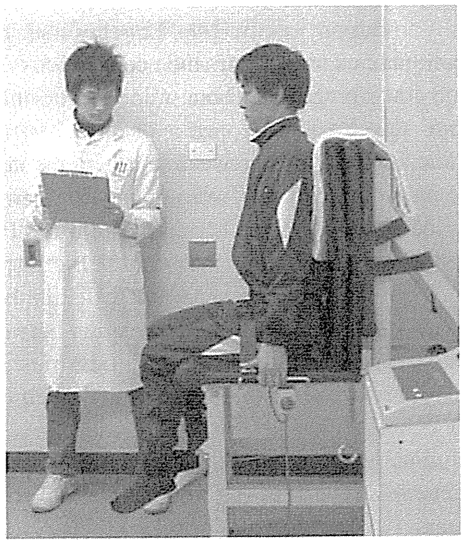

Fig. 1 Isometric knee extension strength was measured in the upright sitting position with knee and hip flexed 90°, using the fixed machine

Statistical analysis

All analyses were conducted using SAS Ver. 9.13 (SAS Institute, Cary, NC, USA). Unpaired Student *t* tests were used to compare characteristics between men and women, and also for the knee extension strength of those who had BMD examinations both at the 2nd and 5th wave and those who did so only at the 2nd. Paired *t* tests were used to compare the BMDs of the subjects at the 2nd and 5th wave.

In the cross-sectional analysis, the correlation between the knee extension strength and BMD at the lumbar spine and femoral neck were tested using Pearson's correlation coefficient controlled for age, square of age, and BMI. Men and women were calculated separately. Trend analysis was made for the change in knee extension strength, according to the age stratum, using a general linear model. As for the longitudinal analysis, multiple logistic regression analyses were conducted. We defined the statistical risk of those who had normal BMD in the initial time (greater than or equal to YMA 80 %) and would become osteopenic or osteoporotic BMD (less than 80 %) after 6 years as the "osteopenia risk." Also, we defined the statistical risk of those who had normal or osteopenic BMD (greater than or equal to YMA 70 %) in the initial time and would develop osteoporosis (BMD less than 70 %) after 6 years as the "osteoporosis risk." "Osteopenia risk and osteoporosis risk" were determined by calculating the odds ratio as a 1 SD decrease in the knee extension strength. Each analysis was conducted controlled for age and BMI.

Results

Characteristics of the subjects were shown in Table 1

Cross-sectional examination; the correlations between knee extension strength and bone mineral densities in the initial time.

Significant correlations between knee extension strength and bone mineral densities were found in men at both lumbar spine and femoral neck, and the adjusted Pearson's correlation coefficients were 0.08 and 0.16, respectively (Table 2). Correlation was rather weak at the lumbar spine. On the other hand, in women the correlation between knee extension strength and bone mineral densities was not significant either in the lumbar spine or in the femoral neck (Table 2).

Longitudinal examination; the associations between the knee extension strength in the initial time and the BMDs after 6 years.

Among 632 men in the group with normal lumbar spine in the initial time, 34 evidenced osteopenia and no men became osteoporotic in 6 years. Among 98 men of the osteopenic group in the initial time, 7 became osteoporotic in 6 years. In the meantime, 48 out of 280 women in the group with normal lumbar spine initially became osteopenic, and 4 women became osteoporotic in 6 years, while 38 out of 134 in the osteopenic group became osteoporotic. As for femoral neck BMD, among 680 men of the normal group in the initial time, 83 showed osteopenia and 7 men became osteoporotic in 6 years. Among 69 in the osteopenic group initially, 30 became osteoporotic in 6 years. In the meantime 116 out of 352 women in the normal group became osteoporotic, and 14 women became osteoporotic in 6 years, while 44 out of 106 in the osteopenic group became osteoporotic.

As for the association between the knee extension strength in the initial time and the BMD at the lumbar spine after 6 years, only the "osteoporosis risk" in men was significant (Table 3), its odds ratio being 2.97 (95 % CI

Table 1 Characteristics of subjects

	Men ($n = 763$)	Women ($n = 476$)	p
Age (years)	57.3 ± 10.2	62.0 ± 8.3	<0.0001
Height (cm)	166.0 ± 6.0	151.6 ± 5.6	<0.0001
Weight (kg)	63.6 ± 8.8	52.2 ± 7.5	<0.0001
BMI (kg/m^2)	23.1 ± 2.7	22.7 ± 3.0	0.0192
Knee extension strength	43.0 ± 10.7	25.9 ± 8.3	<0.0001
BMD at initial time			
Lumbar spine (L2–4) (g/cm^2)	0.984 ± 0.151	0.844 ± 0.143	<0.0001
Femoral neck (g/cm^2)	0.767 ± 0.108	0.667 ± 0.101	<0.0001
BMD after 6 years			
Lumbar spine (L2–4) (g/cm^2)	0.994 ± 0.170	0.817 ± 0.138	<0.0001
Femoral neck (g/cm^2)	0.726 ± 0.111	0.611 ± 0.100	<0.0001

Values are mean ± SD

* $p < 0.0001$

Table 2 Correlation analyses using Pearson's correlation coefficient of knee extensor strength and BMD

	Coefficient	(95 % CI)	p
At lumbar spine			
Men	0.081	(0.011 to 0.152)	0.024
Women	0.015	(−0.075 to 0.105)	0.739
At femoral neck			
Men	0.157	(0.087 to 0.226)	<0.0001
Women	0.022	(−0.068 to 0.112)	0.630

Correlation analyses were made between the knee extensor strength and bone mineral density using Pearson's correlation coefficient controlled for age, square of age, and BMI

Table 3 Association of knee extension strength and BMD change at the lumbar spine

	OR	(95 % CI)	*p*
Osteopenia risk			
Men (*n* = 633)	1.32	(0.86–2.02)	0.21
Women (*n* = 265)	0.78	(0.56–1.09)	0.143
Osteoporosis risk			
Men (*n* = 731)	2.97	(1.07–8.23)	0.036
Women (*n* = 399)	1.08	(0.74–1.55)	0.70

All analyses were conducted controlled for age and BMI

OR odds ratio as 1 strength decreases (SD)

Table 4 Association of knee extension strength and BMD change at the femoral neck

	OR	(95 % CI)	*p*
Osteopenia risk			
Men (*n* = 681)	1.84	(1.36–2.48)	<0.0001
Women (*n* = 336)	1.29	(1.002–1.65)	0.048
Osteoporosis risk			
Men (*n* = 750)	1.50	(0.93–2.42)	0.09
Women (*n* = 442)	1.25	(0.91–1.72)	0.18

All analyses were conducted controlled for age and BMI

OR odds ratio as 1 strength decreases (SD)

1.07–8.23). As for the BMD of the femoral neck, however, a significant effect of knee extension strength was observed in the "osteopenia risk" in both men and women. Their odds ratios were 1.84 (95 % CI 1.36–2.48), and 1.29 (95 % CI 1.002–1.65), respectively. On the other hand there was no significant difference in the "osteoporosis risk" of the femoral neck in both men and women (Table 4).

Discussion

Utilizing a large cohort of local inhabitants, we examined the effects of knee extensor muscle strength on the bone mineral densities in the longitudinal changes, as well as in the cross-sectional studies. In the cross-sectional studies, significant correlations were found in men at both lumbar spine and femoral neck, but not in women. Although we excluded pre-menopausal women in order to avoid the menopausal effect on bone mineral densities, women's bone may be more influenced by something other than the muscle force compared to men; for example, by estrogen decline [32], and also much weaker knee extensor strength in women than in men [33]. Thus, there may not be enough effect on the bone.

We have also examined the effect of knee extension strength on the longitudinal bone loss of the lumbar spine and femoral neck, checking between normal and osteopenia, as well as between osteopenia and osteoporosis. At the femoral neck, the decrease in knee extension strength had a significant effect on whether osteopenia developed or not; however, it failed to show an effect on whether or not it became osteoporosis. This was the case with both sexes. From these results, exercise for strengthening the legs seemed to be good not only for locomotive ability or prevention from falls but also for protecting against bone loss at the proximal femur in the future, particularly when bone was in healthy condition. Quadriceps femoris are the only knee extensor muscle and they originate from both above and below the hip joint. Thus, during knee extension behavior force should be applied to the proximal part of the femur, making it stronger. In the advanced stage of bone loss, however, this effect may not be strong enough.

In the meantime, as for the lumbar spine, the decrease in knee extension strength had a significant effect on whether osteoporosis developed only in men, but not in women. Since this is not site-specific, it may reflect physical activity and the systemic effect on the bone metabolism. The decline of muscle strength in men was more prominent in aging than in women [33], and might affect physical activity more.

As for the relation of muscle strength on longitudinal BMD change, Iki and colleagues [26] demonstrated a site-specific relation of the back in women; trunk muscle strength was related with BMD loss in the lumbar spine during a 4-year period. Since they did not investigate BMD in the hip lesion, they had no results about the site-specific association of muscle strength and bone loss in the lower extremities. In that study, they failed to demonstrate any relation between lumbar BMD and knee extensors, and flexors as well in women, which is consistent with our results at 6 years.

In a study over longer time intervals, Sirola et al. [28] investigated the loss of BMD in the lumbar spine and femoral neck BMD over 10 years. Although the study showed a good relation with grip strength change at both sites, the knee extensor or trunk muscles were not examined, so no mention was made in the site-specific connection.

There are some limitations in this study. First, our response rates were 69.3 % (763 out of 1101) in men, and 65.0 % (476 out of 732) in women. Thus, there may be some difference between the responder (who participated in both the 2nd and 5th wave) and non-responder (who participated only in the 2nd wave). Actually non responders were about 7-year-older than responders. Moreover, knee extension strength was also stronger in the responder, but when we controlled with sex and age, the difference was minimum (only 0.3 kg). Another limitation is that we excluded premenopausal women in order to eliminate the effect of estrogen on bone, which made for a significant age difference between sexes. Our study focused on the relation between knee extensor muscle strength and longitudinal bone loss. However, some factors may influence BMD, like nutrition [4], physical activity [6, 13, 14] or exercise status [7–10]. These might be confounding factors, which should be the next target for investigation.

The strong point of our study is that our samples were randomly selected from people in the local community with very little bias in the selection process. NILS-LSA is one of the few major epidemiological studies for investigating the aging mechanism that is designed to select the subject in a completely random manner, so as to avoid bias when conducting epidemiologic study in many ways.

In summary, we investigated whether or not knee extension strength can predict the incidence of osteopenia or osteoporosis after 6 years, utilizing a large-scale cohort of subjects randomly selected from the local community. We showed the clear effect of muscle strength on BMD loss in the early stage in the femoral neck both in men and women, but not in the lumbar spine. The effect proved to differ by gender; it affected men in the late stage of bone loss in lumbar spine, but not in women. This suggests the importance of knee extension strength to maintain the bone health of the proximal femur and lumbar spine in aging particularly in men.

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Conflict of interest The authors declare that no conflict of interest, with any company and/or other organization, exists pertaining to the article mentioned below regarding the content, conclusion, and significance of the research as well as opinions on them.

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ORIGINAL ARTICLE: EPIDEMIOLOGY, CLINICAL PRACTICE AND HEALTH

Development of an equation for estimating appendicular skeletal muscle mass in Japanese older adults using bioelectrical impedance analysis

Daisuke Yoshida,[1,2] Hiroyuki Shimada,[1] Hyuntae Park,[3] Yuya Anan,[1] Tadashi Ito,[1] Atsushi Harada[4] and Takao Suzuki[5]

[1]Section for Health Promotion, Department for Research and Development to Support Independent Life of Elderly, Center for Gerontology and Social Science, [3]Section for Physical Functioning Activation, Department of Functioning Activation, Center for Gerontology and Social Science, [4]Department of Orthopedic Surgery, National Hospital for Geriatric Medicine, [5]Research Institute, National Center for Geriatrics and Gerontology, and [2]Japan Foundation for Aging and Health, Obu, Japan

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Aim: Bioelectrical impedance analysis has been reported to have high reliability and accuracy in assessing body composition. However, equations for estimating appendicular skeletal muscle mass are population-specific, and few have been developed for older Japanese adults. Thus, the purpose of the present study was to develop and validate an estimate equation for appendicular skeletal muscle mass using bioelectrical impedance analysis.

Methods: A total of 250 older adults aged 65 years and older participated in this study. Appendicular skeletal muscle mass was measured using dual-energy X-ray absorptiometry, and bioelectrical resistance was measured using a multifrequency bioelectrical impedance analyzer. Multiple regression analysis was applied to derive sex-specific estimation formulae using bioelectrical impedance analysis, and a Bland–Altman analysis was used to test agreement.

Results: The cross-validation results showed that the slopes and intercepts of the regression lines were approximately one and zero, respectively, and the coefficients of determination and standard errors of the estimate of the newly developed equations were similar between the two groups. Thus, the single sex-specific equations were developed using all participants as follows. Men: appendicular skeletal muscle mass = 0.197 × (impedance index) + 0.179 × (weight) – 0.019 ($R^2 = 0.87$, standard error of the estimate = 0.98 kg). Women: appendicular skeletal muscle mass = 0.221 × (impedance index) + 0.117 × (weight) + 0.881 ($R^2 = 0.89$, standard error of the estimate = 0.81 kg).

Conclusion: These new equations offer a valid option for assessing appendicular skeletal muscle mass in older Japanese adults. **Geriatr Gerontol Int 2014; 14: 851–857.**

Keywords: aging, bioelectrical impedance, body composition, sarcopenia, skeletal muscle mass.

Introduction

There are several changes in body composition (e.g. a decrease in bone and muscle mass, and an increase in the proportion of fat) that take place during the aging process.[1,2] Lower muscle mass is associated with lower strength, and could lead to the development of functional limitations and disability in old age.[3–6] Advanced skeletal muscle loss might also have the potential to impact quality of life, the need for supportive services and, ultimately, the need for long-term care in older adults.[5] Japan has one of the highest average life expectancies and average active life expectancies in the world. Consequently, it is possible that sarcopenia is more prevalent in Japan compared with other countries. Thus, it is important to assess the change in skeletal muscle mass, and establish a preventive strategy for sarcopenia.

Evidence shows that magnetic resonance imaging, computerized tomography (CT), and dual-energy X-ray absorptiometry (DXA) provide precise and reliable measurements of skeletal muscle, and can be considered as benchmark methods for measuring skeletal muscle.[7]

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Correspondence: Dr Daisuke Yoshida PhD, Section for Health Promotion, Department for Research and Development to Support Independent Life of Elderly, Center for Gerontology and Social Science, National Center for Geriatrics and Gerontology, 35 Gengo, Morioka-machi, Obu, Aichi 474-8511, Japan. Email: yoshida@ncgg.go.jp

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However, cost, accessibility and radiation exposure limit the use of these measurement methods.[8] Conversely, bioelectrical impedance analysis (BIA) is a non-invasive, easily applicable, inexpensive and practical method that is used to assess body composition in population studies.[5] Several studies have also developed BIA equations for estimating whole-body skeletal muscle or fat-free mass (FFM).[8–18] However, most of these equations were derived from Western or young populations, and none have been developed using a representative older Japanese adult sample.

The BIA is convenient to assess body composition in epidemiological studies, but only if population-specific prediction formulas are used.[13] Generalized application to other populations is limited.[19] The BIA equation derived from Caucasians was shown to be applicable to Hispanic and African–Americans, but has not been validated for estimation of skeletal muscle in Asian populations.[10] Therefore, it has been suggested that BIA equations should be developed and validated for population-specific groups.[12] The purpose of the present study was to develop and validate a new BIA equation for estimating appendicular skeletal muscle (ASM) in older Japanese adults.

Methods

Participants

Previously, we carried out a population-based cohort study, the Obu Study of Health Promotion for the Elderly (OSHPE), from August 2011 to February 2012.[20] In the present study, participants were recruited from this existing database ($n = 5104$). Inclusion criteria required participants to be aged 65 years or older and living independently in Obu city, Aichi, Japan. Exclusion criteria were as follows: subjects who participated in other studies, a certified need for long-term care or impairment of activities of daily living, a severe visual or hearing impairment, a medical history (stroke, Parkinson's disease and other serious neurological diagnoses), clinical depression, wearing a pacemaker, or a Mini-Mental State Examination score <18. Finally, a total of 250 subjects aged 65 years and older participated in the present study. All participants were informed about the study procedures and provided written informed consent before participation. In addition, the present study was carried out in accordance with the Helsinki Declaration, and was approved by the ethics committee of the National Center for Geriatrics and Gerontology.

Anthropometric measurements

With the participants wearing light indoor clothes and no shoes, bodyweight was measured to the nearest 0.1 kg using calibrated digital electronic scales, and height was measured to the nearest 0.1 cm using a wall-mounted stadiometer. Body mass index (BMI) was calculated as weight (kg) divided by height (m) squared.

Measurement of bioelectrical impedance

A multifrequency bioelectrical impedance analyzer (MC-980A, Tanita, Tokyo, Japan) was used to measure bioimpedance. The BIA instrument used six electrical frequencies (1 kHz, 5 kHz, 50 kHz, 250 kHz, 500 kHz and 1000 kHz), and we calculated the impedance index, height^2 (cm) divided by resistance (Ω), after measurements were made. The participants stood barefoot on the analyzer platform, grasping the two handgrips. Eight-point tactile electrodes made contact with the palm and thumb of each hand, and with the anterior and posterior aspects of the sole of each foot. Surface electrodes were placed on the right side of the body, on the dorsal surface of the hands and feet proximal to the metacarpal- and metatarsal-phalangeal joints, respectively, and also medially between the distal prominences of the radius and ulna, and between the medial and lateral malleoli at the ankle. Measurements were carried out by well-trained staff, and completed within 30 s.

Previous studies evaluating the short- and long-term reliability of resistance measurements obtained from bioelectrical impedance have shown that the coefficients of variation (CV) were small, and ranged from 1.8% to 2.9%.[21] In the present study, the CV for repeated measurements within 5 days ($n = 3$) was similar to previous studies (CV = 1.9–3.0%).

Assessment of body composition

Whole-body DXA (QDR-4500A; Hologic, Waltham, MA, USA) was used to assess skeletal muscle mass. The system software calculated the total mass, soft tissue attenuation ratios and the bone mineral mass for the selected regions. The soft tissue attenuation ratio was used to divide regional bone mineral-free tissue into fat and fat-free components.

Measurements were carried out by a trained radiology technician with dual-energy X-ray beams at 100 and 140 KeV, and the scan followed the manufacturer's default methodology, with data analyzed using the 9.03D version of software. Participants were measured while wearing only a standard light cotton gown to minimize clothing absorption. The measurement was completed within 15 min.

Total body scanning area was divided into precise anatomical segments. The arms were separated from the trunk by a line passing through the humeral head and the apex of the axilla. The trunk was separated from the legs by a line passing from the iliac crest to the perineum. The head was excluded from the trunk by a horizontal line passing just below the mandible. The

Table 1 Characteristics of the participants

	All participants ($n = 250$)	Men ($n = 141$)	Women ($n = 109$)	P-value[a]
Age (years)	73.5 ± 5.6	73.7 ± 5.7	73.2 ± 5.5	0.47
Height (cm)	156.0 ± 9.0	161.8 ± 6.1	148.5 ± 6.1	<0.01
Weight (kg)	57.0 ± 10.6	61.2 ± 8.8	51.6 ± 10.3	<0.01
BMI (kg/m^2)	23.4 ± 3.4	23.4 ± 3.0	23.4 ± 3.9	0.97
ASM (kg)	17.8 ± 3.8	20.3 ± 2.7	14.6 ± 2.4	<0.01
Percent of body fat (%)	24.9 ± 6.8	21.0 ± 4.6	29.9 ± 5.7	<0.01
Osteoporosis (%)	10.8	5.0	18.3	<0.01
Fractures in old age (%)	13.6	7.1	22.0	<0.01

Values are mean ± standard deviation or %. [a]Significant difference between men and women. ASM, appendicular skeletal muscle mass; BMI, body mass index.

ASM was derived as the sum of fat-free soft tissues in the arms and legs, assuming that all non-fat and non-bone tissue was skeletal muscle.

Visser *et al.* validated the Hologic QDR-4500 instrument in older participants, and found that measured FFM was positively associated with FFM using a four-compartment model ($R^2 = 0.98$, standard error of the estimate [SEE] = 1.6 kg), and with CT at all four leg regions ($R^2 = 0.86$–0.96).[22] Two previous studies also reported that total body skeletal muscle mass could be accurately predicted from DXA-measured appendicular lean soft tissue mass.[23,24] To our knowledge, the CV using the QDR-4500 for measuring body composition has not been previously reported. However, the CV using the QDR-2000 (an old model Hologic) were 1.0% for FFM and 2.0% for fat mass.[25] Repeated daily measurements over 5 days in three participants showed that the CV of this measurement were 1.1% for FFM and 3.0% for fat mass.

Statistical analysis

We compared characteristics between men and women using paired t-tests or χ^2-tests where appropriate. Multiple regression analysis was used to develop sex-specific BIA equations. The ASM measured by DXA was used as the external criterion (dependent variable), and the impedance index that had the highest Pearson's correlation coefficient to the ASM was entered into the BIA model (independent variable). To develop a more precise fitting model, we examined other predictive variables using references to previous studies.[8–18] The anthropometric variable that had the highest Pearson's correlation coefficient to the ASM was also selected as the independent variable.

The BIA equation for estimating ASM was also developed using a double cross-validation technique. The total sample was randomly divided into two equal-sized groups (group A and B). A BIA equation was developed for each group, and then applied to the other group to validate each equation. The mean difference between the DXA-measured and the BIA-estimated ASM was tested using a paired t-test. If the cross-validation was satisfactory, groups were combined and a single equation was developed using all samples. Bland–Altman analysis was also used to test agreement.[26] All analyses were carried out using commercially available IBM SPSS statistics software (Version 19; SPSS, Chicago, IL, USA), and a significance level of $P < 0.05$ was accepted.

Results

Development of the new BIA equation for estimating ASM

Table 1 shows the demographic and anthropometric characteristics of the participants. There were significant sex-differences in height, weight, ASM, percent of fat, and prevalence of osteoporosis and fractures in old age (≥60 years). In the regression model, we selected independent variables based on the results of correlation analyses. Out of the six electrical frequencies, the impedance index at 50 kHz and above had a higher correlation ($r = 0.94$) to DXA-measured ASM compared with other electrical frequencies ($r = 0.91$ at 1 kHz and 5 kHz). With regard to the anthropometric variable, weight had the highest correlation with DXA-measured ASM ($r = 0.88$ for men, $r = 0.89$ for women; Table 2). As a result, the independent variables included impedance index at 50 kHz and weight. Sex-specific BIA equations used to estimate ASM in each group were as follows:

[Men]

$$\text{Group A } (n = 70)\text{: ASM} = 0.200 \times (\text{impedance index}) + 0.187 \times (\text{weight}) - 0.878 \left(R^2 = 0.87, \text{SEE} = 1.01\text{ kg}\right)$$

$$\text{Group B } (n = 71)\text{: ASM} = 0.191 \times (\text{impedance index}) + 0.174 \times (\text{weight}) + 0.816 \left(R^2 = 0.89, \text{SEE} = 0.91\text{ kg}\right)$$

Table 2 Correlation coefficients between appendicular skeletal muscle mass and other variables

		Ht^2/R	Height	Weight	BMI	Age
ASM	Men	0.83**	0.53**	0.88**	0.67**	–0.29**
	Women	0.89**	0.59**	0.89**	0.74**	–0.17

$^*P < 0.05$; $^{**}P < 0.01$. ASM, appendicular skeletal muscle mass; BMI, body mass index; Ht^2/R, impedance index ($height^2$/resistance) at 50 kHz.

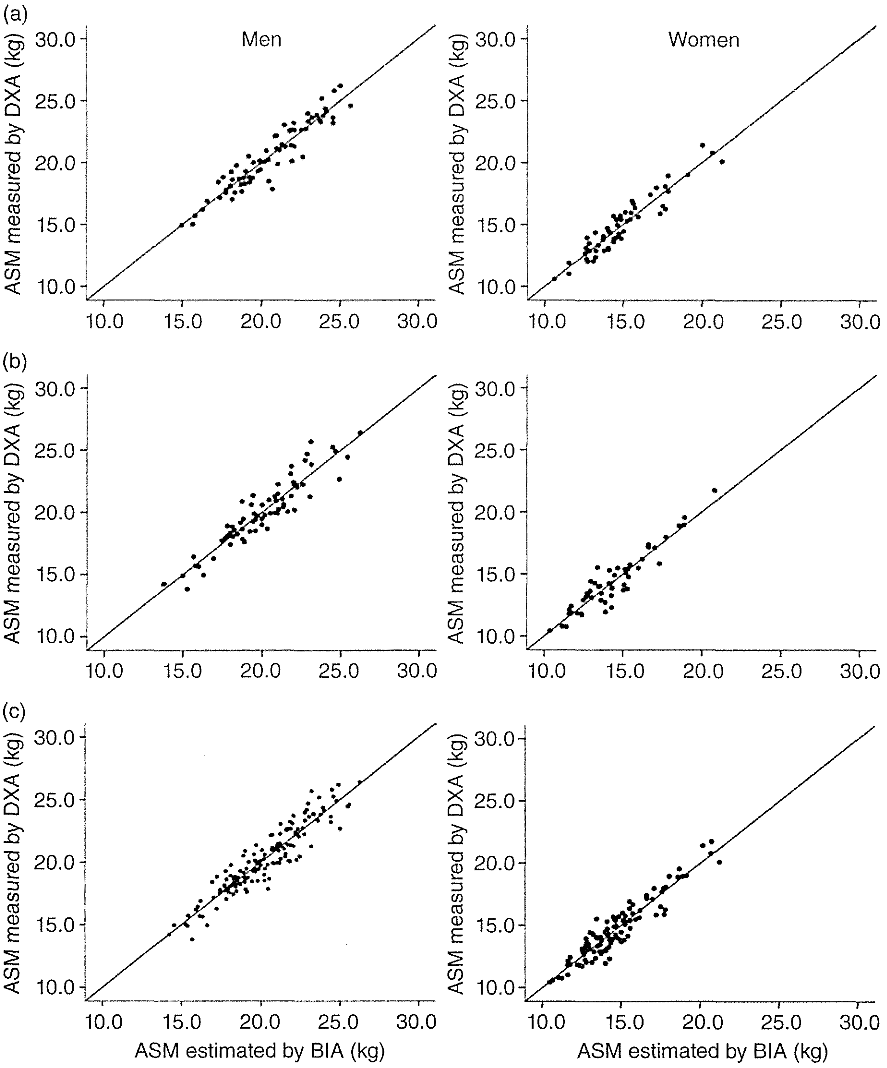

Figure 1 Estimation of appendicular skeletal muscle mass in (a) group A, (b) group B and (c) all participants. Solid line: regression line; dotted line: line of identity. ASM, appendicular skeletal muscle mass; BIA, bioelectrical impedance analysis; DXA: dual-energy X-ray absorptiometry.

[Women]

Group A ($n = 54$): $\text{ASM} = 0.192 \times (\text{impedance index}) + 0.133 \times (\text{weight}) + 1.087 \left(R^2 = 0.88, \text{SEE} = 0.84\ \text{kg}\right)$

Group B ($n = 55$): $\text{ASM} = 0.256 \times (\text{impedance index}) + 0.099 \times (\text{weight}) + 0.558 \left(R^2 = 0.89, \text{SEE} = 0.79\ \text{kg}\right)$

The BIA equations developed in group B were applied to the data of group A (Fig. 1a). Similarly, the BIA equations developed in group A were used to estimate ASM in group B (Fig. 1b). There were no significant differences between the BIA-estimated ASM and the DXA-measured ASM in both groups. The R^2 and SEE values were also similar between the two groups. Furthermore, regressions of BIA-estimated ASM on DXA-measured ASM for each group were almost identical with similar deviations from the line of identity. Thus, single equations using all participants were developed to

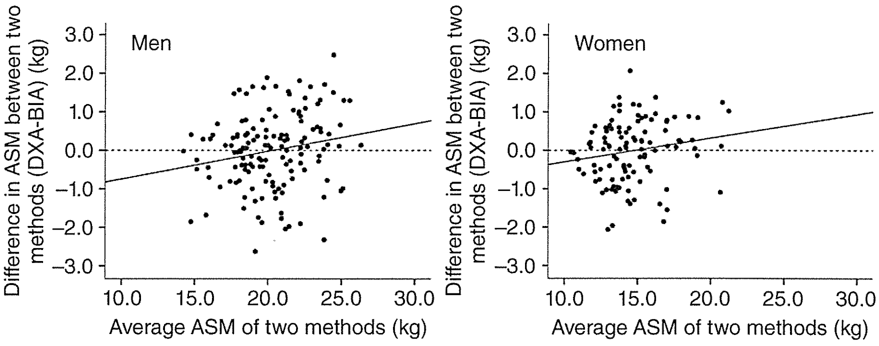

Figure 2 Bland–Altman plot for the difference in appendicular skeletal muscle mass (ASM) between dual-energy X-ray absorptiometry and bioelectrical impedance analysis, and the average ASM of the two methods. Solid line: regression line; dotted line: average difference in ASM between the two methods. BIA, bioelectrical impedance analysis; DXA: dual-energy X-ray absorptiometry.

estimate ASM (Fig. 1c). The BIA equations developed from all participants were as follows:
[Men]

$$ASM = 0.197 \times (\text{impedance index}) + 0.179 \times (\text{weight}) - 0.019.$$ The model fit parameters (R^2 and SEE) were 0.87 and 0.98 kg, respectively.

[Women]

$$ASM = 0.221 \times (\text{impedance index}) + 0.117 \times (\text{weight}) + 0.881.$$ The model fit parameters (R^2 and SEE) were 0.89 and 0.81 kg, respectively.

The mean differences between BIA-estimated and DXA-measured ASM were not significantly different. Systematic differences between the BIA-estimated and the DXA-measured ASM were determined using a Bland–Altman plot (Fig. 2). The BIA method tended to underestimate ASM in participants with high ASM, and overestimate ASM in participants with low ASM, but correlation coefficients between the difference in DXA-measured and BIA-estimated ASM and the average ASM of the two methods were small ($r = 0.19$ for men; $r = 0.17$ for women).

Discussion

Although several studies have developed BIA equations for estimating whole-body skeletal muscle or FFM,[8–18] most of these population-specific and generalized equations were derived from Western or young populations. It has been established that the validity of BIA equations depends on the population to which they are applied, as well as water distribution, fatness, ethnicity and body shape differences.[9] To assess body composition and diagnose sarcopenia more accurately, a BIA equation for estimation of ASM in older Japanese adults is required.

We selected variables for the regression model based on results obtained from correlation coefficients. Correlations were different in each of the six electric frequency bands, and the use of electric frequencies over 50 kHz did not improve performance of the BIA model. We therefore chose an impedance index at 50 kHz, which had the highest correlation ($r = 0.94$) to DXA-measured ASM. From the other potential variables, weight was included as an independent variable.

The new BIA equations explained 87% for men and 89% for women of the variance in DXA-measured ASM, and the model fit parameters were similar or superior to previous results estimating skeletal muscle or FFM by BIA ($R^2 = 0.70$–0.97). A greater contribution of impedance index to DXA-measured ASM was evident in the BIA model.

Bland–Altman analysis showed a tendency of systematic error with the BIA method. This tendency was observed in a previous study with Asian participants,[8] although the errors were small. The present results also showed that the differences between DXA-measured and BIA-estimated ASM ranged from +2.47 kg to −2.63 kg for men, and +2.07 kg to −2.06 kg for women, which are smaller compared with those in previous studies.[8,10] These results suggest that the new equations can provide valid, reliable and accurate estimates of ASM in older Japanese adults. These equations might allow efficient screening to identify sarcopenic patients from large samples, and clarify the prevalence of sarcopenia in older people.

There were some limitations of the current study. First, we could not strictly control the factors that could potentially affect the accuracy of BIA measurement. Despite participants with chronic diseases or prescribed medications being excluded, and most participants maintaining a relatively consistent pattern of lifestyle over the past year, it is likely that the time of measurement[27] and eating or exercise before measurement,[28,29] must be controlled to minimize potential error.[30] Second, we used DXA as the reference method, and estimated ASM using this measurement, and total ASM was taken as the sum of arm and leg values. This estimate included a small and relatively constant amount of skin and connective tissue, together with any intramuscular fat infiltration. Therefore, DXA-measured ASM might overestimate actual muscle mass. Furthermore, as a result of the cross-sectional designs of these findings, the long-term predictive validity of the equation has not yet been evaluated. Thus, subsequent studies will be required to confirm the validity of the equation in longitudinally monitored populations.

In summary, we have developed new BIA equations for estimating ASM, and confirmed the validity of these equations. The cross-validation of the BIA equations was successful, and the magnitude of error in estimating ASM was small. These observations suggest that these new equations offer a valid option to assess ASM in older Japanese adults.

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Disclosure statement

No potential conflicts of interest were disclosed.

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ORIGINAL ARTICLE

Association of grip strength and related indices with independence of activities of daily living in older adults, investigated by a newly-developed grip strength measuring device

Yasumoto Matsui,[1] Remi Fujita,[1] Atsushi Harada,[1] Takashi Sakurai,[2] Tetsuya Nemoto,[3] Nobuo Noda[4] and Kenji Toba[2]

[1]Department of Advanced Medicine (Orthopedic Surgery), [2]Center for Comprehensive Care and Research on Memory Disorders, [3]Department of Gerontechnology, National Center for Geriatrics and Gerontology, Obu, and [4]Eisyo Metal Co., Ltd, Tokyo, Japan

Aim: To investigate the association of grip strength and activities of daily living independence in older adults, using a newly-developed grip strength measuring device.

Methods: Patients who visited the clinic for memory disorders at the National Center for Geriatrics and Gerontology (142 men and 205 women, mean age 74.8 ± 8.8 years) were included in the present study. Their strength during gripping performance is described in detail, and following the indices were calculated: maximum strength (MS), response time (RT), time to MS, time to reach turning point (TP), strength at TP, inclination from start to TP, time from TP to reach MS, inclination from TP to MS and ratio of strength (TP/MS). Barthel Index (BI), total scores and scores of each subclass were used for evaluating activities of daily living independence. MS was compared between the independent and dependent groups. Correlations, using partial Pearson's coefficient adjusted for age, and Mini-Mental State Examination total score were analyzed between indices and BI by sex, side, and age groups.

Results: MS was significantly higher in the independent group. MS and RT were significantly related with BI total and certain subclasses in both hands, TP/MS was significantly related in the right hand of either sex, and strength at TP was significantly related in both hands in women and in the left hand in men. Time to reach TP was particularly correlated in both hands and time from TP to reach MS in the right hand, in men. The correlation of indices varied by sex, hand side and age group, especially in men aged in their 70s, and in women aged less than 70 years and women aged in their 80s.

Conclusion: MS was shown to be useful, but some of the newly defined indices, such as RT, strength at TP, and elements regarding before and after TP until reaching MS, were also suggested to be useful. **Geriatr Gerontol Int 2014; 14 (Suppl. 2): 77–86.**

Keywords: activities of daily living independence, association, detailed evaluation, grip strength, muscle contraction.

Introduction

In geriatric medicine, evaluations of physical ability and assessment as to whether elderly patients keep their independence in activities of daily living (ADL) are essential tasks. They are included in the comprehensive geriatric assessment (CGA),[1] the importance of which has been widely recognized.[2] For the evaluation of physical ability, the grip strength test is one of the most popular and widely utilized methods,[3–5] as it is considered to be an indication of the state of muscle function.[6–9] Grip strength has been reported to be correlated with ADL or physical performance,[10–14] or to predict disability or dependence in the future.[15–18]

In order to assess the gripping ability of physically weakened older adults more precisely, we have developed a new device to analyze the detailed way in which muscles contract during gripping performance.[19] This new device can accurately measure not only very weak peak values, but also the agility or the endurance in gripping by taking the time axis into consideration. Using the data obtained from the measurement by this

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Correspondence: Dr Yasumoto Matsui MD, 35, Gengo, Morioka-cho, Obu, Aichi 474-8511, Japan. Email: matsui@ncgg.go.jp

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