A community-based approach to lean body mass and appendicular skeletal muscle mass prediction using body circumferences in community-dwelling elderly in Taiwan

Running title: Estimation of muscle mass by body circumferences

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ABSTRACT

Background and Objectives: To develop and validate the prediction equations for lean body mass (LBM) and appendicular skeletal muscle mass (ASM) using body circumference measurements of community-dwelling adults older than 50 years old. **Methods and Study Design:** Four hundred and ninety-eight community-dwelling adults older than 50 years old were recruited for this study. Participants were randomly assigned to a development group (DG, n=332) and validation group (VG, n=166). Lean body mass and ASM were assessed using dual-energy x-ray absorptiometry along with the anthropometric parameters. The Pearson correlation coefficient was used to examine the associations between ASM, LBM and anthropometric parameters in the DG. Prediction equations for LBM and ASM were established from DG data using multiple regression analyses. Paired t-test and Bland-Altman test were used to validate the equations in the VG. **Results:** Forearm circumference had the highest correlation with LBM and ASM. The developed prediction models were: LBM (kg) = 27.479 + 0.726 * weight (kg) - 3.383 * gender (male = 1, female = 2) - 0.672 * BMI + 0.514 * forearm circumference (cm) - 0.245 * hip circumference (cm)($r2$=0.90); ASM (kg) = -4.287 + 0.202 * weight (kg) - 0.166 * hip circumference (cm) - 1.484 * gender (male = 1, female = 2) + 0.173 * calf circumference (cm) + 0.096 * height + 0.243 * forearm circumference (cm)($r2$=0.85). **Conclusions:** Prediction equations using only a measuring tape provide accurate, inexpensive, practical methods to assess LBM and ASM in Asians older than 50 years old.

Key Words: appendicular, elderly, nutrition assessment, the regression formula, aging

INTRODUCTION

Lean body mass (LBM) decreases and fat mass increases with ageing after middle-age.[1] Studies indicated that the decrease in muscle mass becomes pronounced at about 50 years old[2] and progresses faster at about 60 years old.[3] Lean body mass is the total body mass minus fat mass, and thus includes the combined weight of the muscles, bone, organs, skin and blood. While increased fat mass is associated with many chronic diseases, the decrease in LBM results in sarcopenia,[2,4-6] metabolic dysfunction, loss of physical function, disability, decreased quality of life and increased mortality.[7-10] In the age-related decrease in LBM, changes in skeletal muscles are the key contributor. Lean body mass is commonly used to reflect the level of whole body skeletal muscle mass in individuals. Appendicular skeletal mass (ASM) accounts for approximately 75% of the total skeletal muscle mass,[11,12] and

receives more attention because it determines the ability of an individual to perform daily physical activities.[13] ASM declines 1 to 2% per year[14] and has been used in the definition of sarcopenia.[7,15] Taken together, LBM and ASM are two common indicators that reflect the amount of muscle mass in both research and in clinics.[6,16-18]

Dual-energy X-ray absorptiometry (DXA), computed tomography (CT) and magnetic resonance imaging (MRI) are accurate methods for measuring body composition. The cost, required techniques and environmental settings are high for these assessment tools, which limit their application in the wider community. Bioelectrical impedance analysis (BIA), compared to the DXA, CT and MRI, is a convenient tool for assessing body composition because it is portable. However, its measurement accuracy is affected by the level of hydration, ambient temperature and the equation used to convert resistance to body density.[19,20] Additionally, BIA equipment is still too expensive for most elderly activity centers.

Anthropometric measurement requires minimal equipment and is a practical way to evaluate body composition. For example, waist circumference (WC) was shown to be correlated with the visceral fat content. Anthropometric parameters have been used to assess nutrition status for a long time.[21] The commonly used parameters in nutritional status assessment include upper arm circumference (UAC), skinfold thickness, and upper arm muscle circumference (UAMC).[22-25] With sarcopenia gaining more attention, the feasibility of using anthropometric measurements to represent muscle mass is examined. To date, several prediction equations for LBM or ASM have been proposed. However, these proposed prediction equations often require limb length,[15] grip strength[18,26] and skinfold thickness[15,27] measurements. The grip strength measurement limitation is the dynamometry device skinfold thickness measurement, often associated with large measurement errors that interfere with the correct interpretation.[21]

In order to promote the practical epidemiological interventional studies on sarcopenia in resource-poor communities, this study developed simple, easily applicable equations, with measures obtained using a measuring tape for LBM and ASM estimation for community-dwelling Asian elderly.

MATERIALS AND METHODS

Participants

Community-dwelling people aged 50 and older were recruited from the Taiwan community. The inclusion criteria were as follows: (1) participants were community-dwelling citizens, and

not hospitalised; (2) participants did not suffer from any major injury or disease that might affect investigations: as examples, those with severe cardiovascular or central nervous system disease were excluded; and (3) participants were able to walk unaided, but assistive devices, such as canes, were permitted when necessary. Four hundred and ninety-eight people participated in this study including 166 males and 332 females. Participants were randomly allocated into the equation development group (DG) (n=332, mean age 68.6±9.30 years old, 109 males, 223 females) and the validation group (VG) (n=166, mean age 68.2±9.27 years old, 57 males, 109 females). This study was approved by the Institutional Review Board of Fu Jen Catholic University (Approval Number: C102050) and Landseed hospital, Taiwan (Approval Number: 14-012-B1). The purpose and procedures of this study were explained to all participants, with formal consents collected.

Anthropometric measurements

Body weight (BW) and standing body height (Ht) were collected to the nearest 0.1 kg and 0.1 cm while wearing thin clothes and no shoes. BMI was calculated as weight (kg) divided by square of height (m2). Circumferences of the upper arm, forearm, waist, hip, thigh and calf were performed using an inelastic plastic tape to the nearest 0.1 cm. Upper arm circumference (UAC) was measured at the midpoint between the acromion and the olecranon. Forearm circumference (FAC) was measured at one-third point between the radial head and radial styloid process with the forearm in the supination position. Waist circumference (WC) was measured at the midline between the iliac crest and last rib margin. Hip circumference (HC) was measured at the widest part of the buttock in standing position with feet together. Thigh circumference (TC) was measured at midpoint between the anterior superior iliac spine and the patella. Calf circumference (CC) was measured at proximal one-third point between the fibular head and lateral malleolus with calf muscles relaxed (Figure 1). Limb circumferences were measured twice on the right-hand side of the body. A third measurement was made if the difference between the first two measurements exceeded 0.5 cm. The average of the two closest values was used for analysis. Anthropometric measurements were performed by two well-trained researchers. Our preliminary study with 90 participants showed an excellent inter-rater reliability (ICC=0.82) for the anthropometric measurements.

Dual-energy X-ray absorptiometry measurements

Lean body mass (LBM) and appendicular skeletal muscle mass (ASM) were measured using DXA (Lunar DPX, lunar corporation, Madison, USA) according to the manufacturer's directions.

Statistical analysis

Data were expressed as mean ± standard deviation. Independent sample t-test was used to determine the difference in outcome variables between the DG and the VG. Pearson correlation coefficient was used to examine the associations between ASM, LBM and anthropometric parameters in the DG group. Backward regression analysis was used to generate LBM and ASM prediction equations from the full models where gender, Ht, BW, BMI, UAC, FAC, WC, HC, TC, and CC were possible predictors. The predictor with the largest p value was dropped and the model was refitted. Paired t-test was used to determine the differences in ASM and LBM between the values derived from the prediction equations and from the DXA measurement in VG. Bland-Altman plots and Lin's concordance correlation coefficient were used to determine the agreement between circumference-predicted LBM/ASM and DXA-measured LBM/ASM. All analyses were performed using SPSS version 20.0 (IBM, Chicago, IL) and statistical significance was set at $\alpha=0.05$ ($p<0.05$).

RESULTS

The mean age of all participants was 69.2±0.8 years (range 63 to 79 years), BMI was 25.0 ± 0.5 kg/m^2, and WC was 88.6±1.6 cm for men and 85.3±1.3 cm for women. Participant characteristics were similar between the DG and the VG (Table 1). Both LBM and ASM were positively correlated with the body height, BW, BMI, and all body circumference measurements. Specifically, circumferences of distal limbs (e.g. forearm and calf) had moderate to high correlation with LBM and ASM (coefficient values were between 0.60~0.72) whereas trunk and proximal limb circumferences had low to moderate correlation with LBM and ASM (coefficient values were between 0.30~0.43) (Table 2). Based on the data from the DG, five predictors gender, BW, BMI, FAC and HC were identified for LBM. The prediction model is presented in Table 3 with high adjusted R^2 (0.90) and low standard error of the estimate (SEE) (0.31 kg). For the ASM prediction six predictors gender, BW, Ht, FAC, CC and HC were identified. The prediction model is presented in Table 3 with high adjusted R2 (0.85) and low SEE (0.37 kg).

   Data from the VG were applied to cross-validate the prediction equations and we found no difference between the DXA-measured LBM/ASM and the circumference-predicted

LBM/ASM (Table 4). Bland and Altman plots from the VG group showed high agreement between DXA-measured LBM/ASM and circumference-predicted LBM/ASM (Figure 1 and Figure 2). There was no significant association between the difference in DXA-measured and circumference-predicted LBM and the average LBM of two methods (r=0.04, *p*=0.63). Similarly, there was no significant association between the difference in DXA-measured and circumference-predicted ASM and the average ASM of two methods (r=0.12, *p*=0.14). The mean difference between the measured and prediction values for LBM and ASM were -0.20±2.27 and 0.03±1.536 kg, respectively.

DISCUSSION

The sarcopenia is the centrum of frailty and an independent risk factor for functional limitation, falls and loss of independence for the elderly. To overcome LBM and ASM assessment barriers in the community setting due to lack of instrumentation, we aimed to develop valid prediction models to predict LBM and ASM from anthropometric measurements that are easily and correctly collected. Using DXA-measured LBM and ASM as references, we developed equations with satisfactory prediction qualities to predict LBM and ASM by gender, Ht, BW, BMI, HC, FAC, and CC. The predictors identified in this study are easily measured and can be performed in the setting with limited resources and only with trained volunteers.

The strength of the equations developed in this study is that with only a body weight and height scale and a measuring tape, the LBM/ASM of Asian community-dwelling people aged 50 and older can be estimated with good predictive quality. Several prediction equations for LBM or ASM based on anthropometric measures have been proposed.[15,18,26-28] However, some limitations existed in the practical application of these equations. First, these proposed prediction equations often required limb length,[15] grip strength[18,26] and skinfold thickness[15,27] measurements. For example, predictors identified by Wen et al. for ASM of Asian adults included limb length and skinfold thickness in addition to limb circumferences.[15] Predictors identified by Furushima et al. for ASM of Asian adults included handgrip strength in addition to BW and waist circumference.[18] Dynamometry is not available for most community settings and reliable skinfold thickness measurements are hard to obtain using community volunteers. We developed appropriate equations using only minimal equipment. While the equations developed by Wen et al showed high correlation (adjusted R^2=0.93) and the equations developed by Furushima et al showed moderate to high correlation (adjusted R^2=0.88 for men and 0.74 for women), the equations developed in this study show comparable predictive value

(adjusted R^2 is 0.9 for LBM and 0.85 for ASM) without limb length, grip strength and skinfold thickness in our prediction models. Another limitation of the existing LMB or ASM prediction models for Asians were developed based on a wide age range population. For example, anthropometric equations for ASM in Chinese adults and Japanese adults were developed from a Chinese population aged 18-69 years old (mean age of women was 41.1 years old and mean age of men was 39.3 years old). The Japanese population was aged 20-90 years old (mean age of women was 54 years old and mean age of men was 48 years old).[15,26] Considering that changes in muscle mass are not linear and the rapid loss in muscle mass occurs at the end of the fifth decade,[13] the equation developed in this study based on participants aged from 50 to 103 years old (mean age 68.6 years old) would be more suitable for middle-aged and elderly individuals.

We found that distal limb circumferences had higher correlation with LBM and ASM than trunk and proximal limb circumferences. FAC was a positive predictor for both LBM and ASM. This finding is similar to a report where cadavers were investigated. Martin et al. found that forearm circumference has greater correlation with total skeletal muscle mass than upper arm circumference in male cadavers.[29] The lower correlation between trunk and proximal limbs circumferences with LBM/ASM than distal limb circumferences is likely due to greater adipose tissue deposition in the trunk and proximal limbs than distal limbs (REF). Waist circumference has been used to define central obesity and the HC is used to indicate the adiposity of individuals.[30] Similarly, obese individuals were found to have greater adipose tissue deposition in the thigh including subcutaneous, subfascial and intermuscular compartments compared to lean individuals.[31] Therefore, our data together with others suggest that trunk and proximal limb circumferences are better indicators for obesity while distal limb circumferences are better indicators for sarcopenia.

An important finding of this study is that FAC was a positive predictor for both LBM and ASM. HC is a negative predictor for both LBM and ASM and CC was a predictor for ASM. Several studies have examined the predictive role of CC for muscle mass and identified CC as a predictor in the estimation model for muscle mass.[26,28,29] FAC is the anthropometric measure that few studies considered. The positive predictive role of FAC on muscle mass has been reported in male cadavers[29] and elderly women.[27] FAC was also found as a negative predictor of body fat in the adult population.[22] Thus, FAC seems like a good indicator of body composition. This finding is exciting because distal limb circumference measurement is easier and more applicable in a community setting compared to the proximal limbs measurement. It is always difficult to ask older people to remove heavy clothes during winter. The reason for

the negative role of HC in the muscle mass estimation is that HC is an indicator of adiposity. In fact, HC has been identified as a negative predictor for muscle mass[26-28] and positive predictor for fat mass.[22] It has been shown that excessive adipose tissue accumulation results in systemic chronic low-grade inflammation and insulin resistance, which increases protein degradation and muscle mass loss.[32,33]

In our developed estimation equations male and higher BW are positive predictors in LBM and ASM equations. This finding is not surprising because muscle mass is greater in males than in females[34] and body weight is the sum of all bodily components. Body weight and gender were included in almost every estimated muscle mass equation using BIA[35-40] or anthropometric measurements.[15,18,26,35,36,38,41]

One limitation of using the ASM prediction equation developed in this study is peripheral edema because it might confound the CC measurement. Another limitation is that the prediction equation developed in this study may only be applicable for Asian individuals older than 50 years old.

Conclusions

This study showed that LBM and ASM can be estimated from anthropometric measurements using only a body weight and height scale and an inelastic plastic measuring tape. LBM and ASM prediction equations were developed and cross-validated using Asians over 50 years old. The prediction equations have the advantage of accuracy, inexpensive, not invasive and easily applied and thus suitable in epidemiological studies and practices in the community.

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CONFLICT OF INTEREST AND FUNDING DISCLOSURE

REFERENCES

1. Houston DK, Nicklas BJ, Ding J, Harris TB, Tylavsky FA, Newman AB, Lee JS, Sahyoun NR, Visser M, Kritchevsky SB; Health ABC Study. Dietary protein intake is associated with lean mass change in

older, community-dwelling adults: the health, aging, and body composition (Health ABC) study. Am J Clin Nutr. 2008;87:150-55. doi: 10.1093/ajcn/87.1.150.

2. Lexell J, Taylor CC, Sjöström M. What is the cause of the ageing atrophy?: total number, size and proportion of different fiber types studied in whole vastus lateralis muscle from 15-to 83-year-old men. J Neurol Sci. 1988;84:275-94. doi: 10.1016/0022-510x(88)90132-3.

3. Frontera WR, Hughes VA, Fielding RA, Fiatarone MA, Evans WJ, Roubenoff R. Aging of skeletal muscle: a 12-yr longitudinal study. J Appl Physiol 2000;88:1321-26. doi: 10.1152/jappl.2000.88.4.1321.

4. Janssen I, Heymsfield SB, Baumgartner RN, Ross R. Estimation of skeletal muscle mass by bioelectrical impedance analysis. J Appl Physiol 2000;89:465-71. doi: 10.1152/jappl.2000.89.2.465.

5. Wolfe RR. The underappreciated role of muscle in health and disease. Am J Clin Nutr. 2006;84:475-82. doi: 10.1093/ajcn/84.3.475.

6. Cruz-Jentoft AJ, Baeyens JP, Bauer JM, Boirie Y, Cederholm T, Landi F et al. Sarcopenia: European consensus on definition and diagnosisreport of the European working group on sarcopenia in older people. Age Ageing. 2010;39:412-23. doi: 10.1093/ageing/afq034.

7. Baumgartner RN, Koehler KM, Gallagher D, Romero L, Heymsfield SB, Ross RR, Garry PJ, Lindeman RD. Epidemiology of sarcopenia among the elderly in New Mexico. Am J Epidemiol. 1998;147:755-63. doi: 10.1093/oxfordjournals.aje.a009520.

8. Janssen I, Heymsfield SB, Ross R. Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability. J Am Geriatr Soc. 2002;50:889-96. doi: 10.1046/j.1532-5415.2002.50216.x.

9. Zamboni M, Mazzali G, Fantin F, Rossi A, Di FV. Sarcopenic obesity: a new category of obesity in the elderly. Nutr Metab Cardiovasc Dis. 2008;18:388-95. doi: 10.1016/j.numecd.2007.10.002.

10. Stenholm S, Harris TB, Rantanen T, Visser M, Kritchevsky SB, Ferrucci L. Sarcopenic obesity-definition, etiology and consequences. Curr Opin Clin Nutr Metab Care. 2008;11:693. doi: 10.1097/MCO.0b013e328312c37d.

11. Synder WS, Cook MJ, Nasset ES, Kahrhausen LR, Howells GP, Tipon LH. Report of the task group on reference man: pergamon press. Oxford; 1975.

12. Al-Gindan YY, Hankey CR, Leslie W, Govan L, Lean ME. Predicting muscle mass from anthropometry using magnetic resonance imaging as reference: a systematic review. Nutr Rev. 2014;72:113-26. doi: 10.1111/nure.12096.

13. Gallagher D, Visser M, De Meersman RE, Sepúlveda D, Baumgartner RN, Pierson RN, Harris T, Heymsfield SB. Appendicular skeletal muscle mass: effects of age, gender, and ethnicity. J Appl Physiol. 1997;83:229-39. doi: 10.1152/jappl.1997.83.1.229.

14. Hughes VA, Frontera WR, Roubenoff R, Evans WJ, Singh MA. Longitudinal changes in body composition in older men and women: role of body weight change and physical activity. Am J Clin Nutr. 2002;76:473-81. doi: 10.1093/ajcn/76.2.473.

15. Wen X, Wang M, Jiang CM, Zhang YM. Anthropometric equation for estimation of appendicular skeletal muscle mass in Chinese adults. Asia Pac J Clin Nutr. 2011;20:551-56. PMID: 22094840.

16. Baumgartner RN. Body composition in healthy aging. Ann NY Acad Sci. 2000;904:437-48. doi: 10.1111/j.1749-6632.2000.tb06498.x.

17. Visvanathan R, Chapman I. Preventing sarcopaenia in older people. Maturitas. 2010;66:383-88. doi: 10.1016/j.maturitas.2010.03.020.

18. Furushima T, Miyachi M, Iemitsu M, Murakami H, Kawano H, Gando Y, Kawakami R, Sanada K. Development of prediction equations for estimating appendicular skeletal muscle mass in Japanese men and women. J Physiol Anthropol. 2017;36:34. doi: 10.1186/s40101-017-0150-x.

19. Vilaça KH, Paula FJ, Ferriolli E, Lima N, Marchini, JS, Moriguti JC. Body composition assessment of undernourished older subjects by dual-energy x-ray absorptiometry and bioelectric impedance analysis. J Nutr Heal Aging. 2011;15:439-43. doi: 10.1007/s12603-010-0300-x.

20. Kyle UG, Bosaeus I, De Lorenzo AD, Deurenberg P, Elia M, Gómez JM et al. Bioelectrical impedance analysis—part I: review of principles and methods. Clin Nutr. 2004;23:1226-43. doi: 10.1016/j.clnu.2004.06.004.

21. Ulijaszek SJ, Kerr DA. Anthropometric measurement error and the assessment of nutritional status. Br J Nutr. 1999;82:165-77. doi: 10.1017/s0007114599001348.

22. Kanellakis S, Skoufas E, Khudokonenko V, Apostolidou E, Gerakiti L, Andrioti MC, Bountouvi E, Manios Y. Development and validation of two equations based on anthropometry, estimating body fat for the Greek adult population. Obesity. 2017;25:408-16. doi: 10.1002/oby.21736.

23. Grellety E, Golden MH. Weight-for-height and mid-upper-arm circumference should be used independently to diagnose acute malnutrition: policy implications. BMC Nutr. 2016;2:10. doi: 10.1186/s40795-016-0049-7.

24. Bishop CW, Bowen PE, Ritchey S. Norms for nutritional assessment of American adults by upper arm anthropometry. Am J Clin Nutr. 1981;34:2530-39. doi: 10.1093/ajcn/34.11.2530.

25. Schaap LA, Quirke T, Wijnhoven HA, Visser M. Changes in body mass index and mid-upper arm circumference in relation to all-cause mortality in older adults. Clin Nutr. 2018;37:2252-59. doi: 10.1016/j.clnu.2017.11.004.

26. Lera L, Albala C, Ángel B, Sanchez H, Picrin Y, Hormazabal MJ, Quiero A. Anthropometric model for the prediction of appendicular skeletal muscle mass in Chilean older adults. Nutr Hosp. 2014;29:611-17. doi: 10.3305/nh.2014.29.3.7062.

27. Pereira PMG, da Silva GA, Santos GM, Petroski EL, Geraldes AA. Development and validation of anthropometric equations to estimate appendicular muscle mass in elderly women. Nutr J. 2013;12:92. doi: 10.1186/1475-2891-12-92.

28. Kulkarni B, Kuper H, Taylor A, Wells, JC, Radhakrishna KV, Kinra S, Ben-Shlomo Y, Smith GD, Ebrahim S, Byrne NM, Hills AP. Development and validation of anthropometric prediction equations for estimation of lean body mass and appendicular lean soft tissue in Indian men and women. J Appl Physiol. 2013;115:1156-62. doi: 10.1152/japplphysiol.00777.2013.

29. Martin AD, Spenst LF, Drinkwater DT, Clarys JP. Anthropometric estimation of muscle mass in men. Med Sci Sports Exerc. 1990;22:729-33. doi: 10.1249/00005768-199010000-00027.

30. Madden A, Smith S. Body composition and morphological assessment of nutritional status in adults: a review of anthropometric variables. J Hum Nutr Diet. 2016;29:7-25. doi: 10.1111/jhn.12278.

31. Goodpaster BH, Thaete FL, Kelley DE. Thigh adipose tissue distribution is associated with insulin resistance in obesity and in type 2 diabetes mellitus. Am J Clin Nutr. 2000;71:885-92. doi: 10.1093/ajcn/71.4.885.

32. Kalinkovich A, Livshits G. Sarcopenic obesity or obese sarcopenia: a cross talk between age-associated adipose tissue and skeletal muscle inflammation as a main mechanism of the pathogenesis. Ageing Res Rev. 2017;35:200-21. doi: 10.1016/j.arr.2016.09.008.

33. Zhou J, Liu B, Liang C, Li YX, Song YH. Cytokine signaling in skeletal muscle wasting. Trends Endocrinol Metab. 2016;27:335-47. doi: 10.1016/j.tem.2016.03.002.

34. Janssen I, Heymsfield SB, Wang Z, Ross R. Skeletal muscle mass and distribution in 468 men and women aged 18–88 yr. J Appl Physiol. 2000;89:81-8. doi: 10.1152/jappl.2000.89.1.81.

35. Peniche DBR, Giorguli GR, Alemán-Mateo H. Accuracy of a predictive bioelectrical impedance analysis equation for estimating appendicular skeletal muscle mass in a non-Caucasian sample of older people. Arch Gerontol Geriatr. 2015;61:39-43. doi: 10.1016/j.archger.2015.03.007.

36. Sergi G, De Rui M, Veronese N, Bolzetta Fr, Berton L, Carraro S, Bano G1, Coin A, Manzato E, Perissinotto E. Assessing appendicular skeletal muscle mass with bioelectrical impedance analysis in free-living Caucasian older adults. Clin Nutr. 2015;34:667-73. doi: 10.1016/j.clnu.2014.07.010.

37. Kim JH, Choi SH, Lim S, Kim KW, Lim JY, Cho NH, Park KS, Jang HC. Assessment of appendicular skeletal muscle mass by bioimpedance in older community-dwelling Korean adults. Arch Gerontol Geriatr. 2014;58:303-7. doi: 10.1016/j.archger.2013.11.002.

38. Kyle U, Genton L, Hans D, Pichard C. Validation of a bioelectrical impedance analysis equation to predict appendicular skeletal muscle mass (ASMM). Clin Nutr. 2003;22:537-43. doi: 10.1016/s0261-5614(03)00048-7.

39. Villani AM, Crotty M, Cameron ID, Kurrle SE, Skuza PP, Cleland LG, Cobiac L, Miller MD. Appendicular skeletal muscle in hospitalised hip-fracture patients: development and cross-validation of anthropometric prediction equations against dual-energy X-ray absorptiometry. Age Ageing. 2014;43:857-62. doi: 10.1093/ageing/afu106.

40. Yoshida D, Shimada H, Park H, Anan Y, Ito T, Harada A, Suzuki T. Development of an equation for estimating appendicular skeletal muscle mass in Japanese older adults using bioelectrical impedance analysis. Geriatr Gerontol Int. 2014;14:851-57. doi: 10.1111/ggi.12177.

41. Yu S, Visvanathan T, Field J, Ward LC, Chapman I, Adams R, Wittert G, Visvanathan R. Lean body mass: the development and validation of prediction equations in healthy adults. BMC Pharmacol Toxicol. 2013;14:53. doi: 10.1186/2050-6511-14-53.

Table 1. Comparisons of anthropometric measurements between DG and VG

	Development group (n=332) (male=32.8%, female=67.2%)		Validation group (n=166) (male=34.3%, female=65.7%)		*p* value
	Mean	SD	Mean	SD	
Age (years)	68.6	9.30	68.2	9.27	0.708
Ht (m)	157.3	7.87	158.0	7.99	0.448
BW (kg)	61.0	10.33	61.6	11.16	0.548
BMI (kg/m^2)	24.6	3.32	24.7	3.96	0.843
UAC (cm)	28.4	2.98	28.5	3.49	0.595
FAC (cm)	22.9	2.35	22.9	2.33	0.851
WC (cm)	86.7	10.00	86.5	11.12	0.843
HC (cm)	94.4	6.67	95.1	7.61	0.305
TC (cm)	48.5	4.70	48.8	5.07	0.512
CC (cm)	34.1	2.99	34.1	3.22	0.947
LBM (kg)	38.3	7.33	38.4	7.28	0.953
ASM (kg)	16.4	3.56	16.4	3.56	0.579

DG: development group; VG: validation group; Ht: body height; BW: body weight; BMI: body mass index; UAC: upper arm circumference; FAC: forearm circumference; WC: waist circumference; HC: hip circumference; TC: thigh circumference; CC: calf circumference; LBM: lean body mass; ASM: appendicular skeletal muscle mass.

Table 2. Correlations between ASM, LBM and anthropometric parameters

	Age (yrs)	Ht (m)	BW (kg)	BMI (kg/m^2)	UAC (cm)	FAC (cm)	WC (cm)	HC (cm)	TC (cm)	CC (cm)	LBM (kg)	ASM (kg)
Age (yrs)	1.000	-0.117[*]	0.009	0.098	-0.091	-0.017	0.296[*]	0.011	-0.215[*]	-0.195[*]	0.011	-0.014
Ht (m)		1.000	0.565[*]	- 0.026	0.207[*]	0.449[*]	0.186[*]	0.125[*]	0.237[*]	0.404[*]	0.765[*]	0.742[*]
BW (kg)			1.000	0.805[*]	0.695[*]	0.762[*]	0.744[*]	0.739[*]	0.645[*]	0.728[*]	0.803[*]	0.767[*]
BMI (kg/m2)				1.000	0.690[*]	0.599[*]	0.775[*]	0.820[*]	0.608[*]	0.585[*]	0.423[*]	0.397[*]
UAC (cm)					1.000	0.737[*]	0.597[*]	0.664[*]	0.677[*]	0.638[*]	0.430[*]	0.410[*]
FAC (cm)						1.000	0.585[*]	0.520[*]	0.597[*]	0.682[*]	0.720[*]	0.704[*]
WC (cm)							1.000	0.706[*]	0.445[*]	0.448[*]	0.477[*]	0.426[*]
HC (cm)								1.000	0.667[*]	0.589[*]	0.333[*]	0.302[*]
TC (cm)									1.000	0.707[*]	0.418[*]	0.413[*]
CC (cm)										1.000	0.597[*]	0.615[*]
LBM (kg)											1.000	0.961[*]
ASM (kg)												1.000

Ht: body height; BW: body weight; BMI: body mass index; UAC: upper arm circumference; FAC: forearm circumference; WC: waist circumference; HC: hip circumference; TC: thigh circumference; CC: calf circumference; LBM: lean body mass; ASM: appendicular skeletal muscle mass.

[*]Significant at an α value of <0 .01.

Table 3. Prediction models for LBM and ASM based on data from the Development Group

Parameters	Adjusted R^2	SEE	Equation
LBM (kg)	0.90	0.31	27.479 + 0.726*BW (kg) - 3.383*gender (male = 1, female = 2) - 0.672*BMI + 0.514*FAC (cm) - 0.245*HC (cm)
ASM (kg)	0.85	0.37	-4.287 + 0.202*BW (kg) - 0.166*HC (cm) - 1.484* gender (male = 1, female = 2) + 0.173*CC (cm) + 0.096 * Ht (cm) + 0.243*FAC (cm)

LBM: lean body mass; ASM: appendicular skeletal muscle mass; BW: body weight; BMI: body mass index; CC: calf circumference; FAC: forearm circumference; HC: hip circumference; Ht: body height; SEE: standard error of the estimate

Table 4. Comparisons between the circumference-predicted LBM/ASM and DXA-measured LBM/ASM in the Validation Group

	DXA-measured values			circumference-predicted values			p value	Lin's CCC
	n	Mean	SD	n	Mean	SD		
LBM (kg)	162	38.34	7.19	162	38.53	7.08	0.366	0.924
ASM (kg)	162	16.57	3.48	162	16.54	3.30	0.798	0.898

LBM: lean body mass; ASM: appendicular skeletal muscle mass; DXA: Dual-energy X-ray absorptiometry; Lin's CCC: Lin's concordance correlation coefficient.
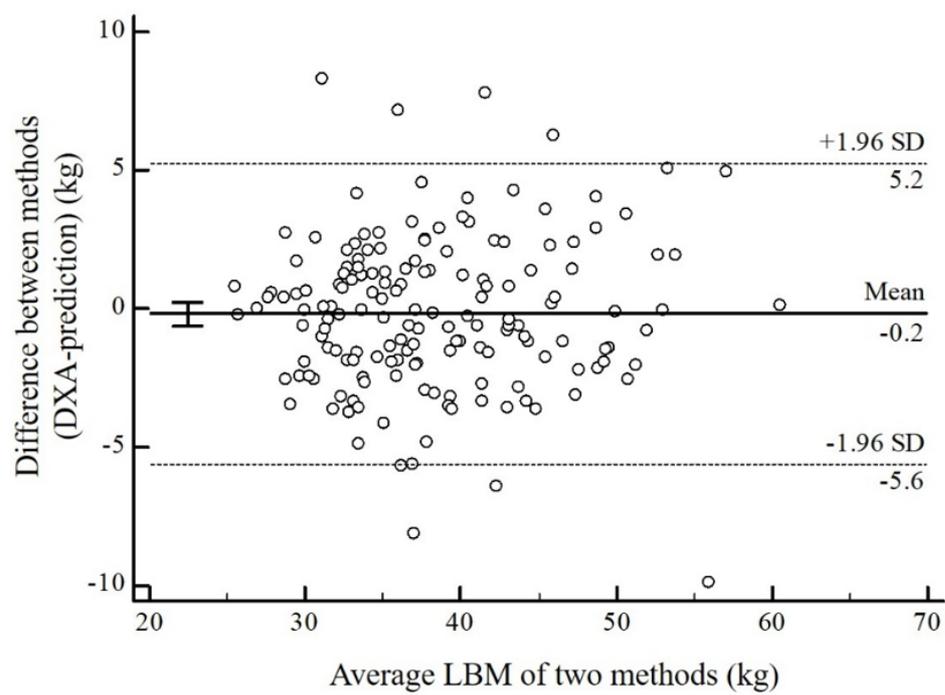
Figure 1. Bland-Altman plot of lean body mass (LBM) measured by DXA and predicted by the prediction equation.
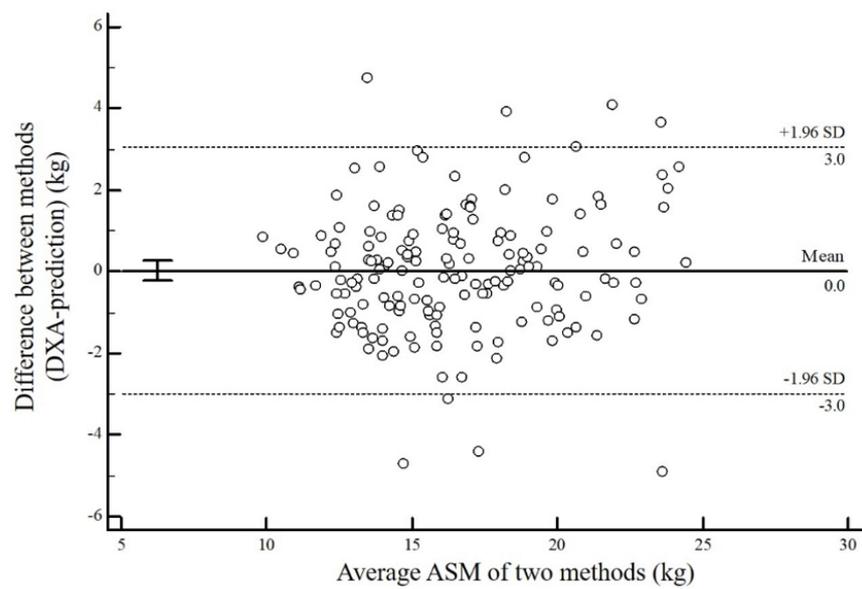
Figure 2. Bland-Altman plot of appendicular skeletal muscle mass (ASM) measured by DXA and predicted by the prediction equation.