Original Article

Anthropometric equation for estimation of appendicular skeletal muscle mass in Chinese adults

Xu Wen PhD[1], Mei Wang MEd[2], Chong-Min Jiang PhD[2], Yi-Min Zhang PhD[3]

[1]Department of Physical Education, Zhejiang University, Hangzhou, China
[2]China Institute of Sports Science, Beijing, China
[3]Beijing Sport University, Beijing, China

The purpose of this study was to develop and cross-validate anthropometric equations for the estimation of appendicular skeletal muscle mass (ASM) in Chinese adults. A total of 763 adults aged 18-69 years (345 men and 418 women) were recruited from residents living in four regions (Jinan, Guangzhou, Xi'an and Chengdu) in China. ASM were measured by fan-beam dual energy x-ray absorptiometry. Participants' body weight, height, limb circumferences (upper arm, thigh, and calf), waist circumference, and skinfold thicknesses (triceps, thigh, and calf) were measured by trained testers. The participants were randomly assigned to two groups: a model-development group (MD group) and a cross-validation group (CV group). Prediction models were established using the data from the MD group, and cross-validated with the data of the CV group. The results suggested that the developed equations had satisfactory prediction qualities, and could be applied as a practical method of quantifying ASM in Chinese adults.

Key Words: skeletal muscle mass, prediction model, body composition, anthropometry, skinfold

INTRODUCTION

Skeletal muscle mass, a key component of body composition in human, is highly correlated to physical function and health status.[1,2] Sarcopenia, which is characterized by the loss of skeletal muscle mass and strength during aging, was found to be associated with low endurance capacity, physical disability, poor quality of life and death.[3-5] The direct healthcare cost for sarcopenia in the United States was estimated to be $18.5 billion in 2000.[6] Therefore, accurate and practical measurement of skeletal muscle mass is very important for research and clinical practice relating to sarcopenia.

Imaging methods such as computerized axial tomography (CT) and magnetic resonance imaging (MRI) have been reported to have excellent accuracy in measuring skeletal muscle mass.[7] Dual energy X-ray absorptiometry (DXA) also provides precise and reliable measurement of skeletal muscle mass.[8,9] Appendicular skeletal muscle mass (ASM) measured by DXA is an important indicator for body muscle mass, and is widely applied in the diagnosis of sarcopenia.[10,11] Nevertheless, CT, MRI and DXA are impractical for large epidemiologic studies due to high cost, radiation exposure and lack of access to instruments. Simple, valid, reliable and inexpensive methods for skeletal muscle mass measurement are still needed. Bioelectrical impedance analysis (BIA) method was proposed for the estimation of muscle mass,[12] because it is portable and noninvasive. However, the validity of BIA in determining body composition is not high.[13] Practical alternative for muscle mass estimation could be anthropometry. Several prediction models were developed to predict total skeletal muscle mass from appendicular circumferences and skinfold thickness, which were proved to be valuable tools for muscle mass estimation.[14-16] However, as these developed prediction equations are population specific, the models may not be applicable to the muscle mass estimation in Asian populations because of ethnic difference in skeletal muscle mass.[17] In addition, ASM is an important parameter to reflect the body skeletal muscle mass level, and is commonly used in the definition of sarcopenia.[10,11] Therefore, the purpose of this study was to develop and cross-validate anthropometric equations for estimation ASM in Chinese adults.

MATERIALS AND METHODS

Study design and participants

The data analyzed in this study is that from a national survey on body composition in the Chinese population. The cross-sectional survey was conducted by physical fitness centers of local governments in four regions (Jinan, Guangzhou, Xi'an and Chengdu) in the P R. China in 2006. A total of 763 adults aged 18-69 years old (345 men and 418 women) were recruited from the residents living in the four regions. Participants with physical disability or those receiving medications that may influence

Corresponding Author: Dr Xu Wen, Department of Physical Education, Zhejiang University, Hangzhou, China.
Tel: 86-15868166812; Fax: 86-571-88273187
Email: wenxu@zju.edu.cn
Manuscript received 29 November 2010. Initial review completed 20 June 2011. Revision accepted 12 July 2011.

their body composition were excluded from the survey. All participants completed informed consent statements approved by the institutional review board. The participants were randomly assigned to two groups: a model-development group (MD group) and a cross-validation group (CV group). Three prediction models (limb-length-circumference model, height-circumference model and height-weight model) were established using the data from the MD group, and cross-validated with the data from the CV group. The rationale for developing three different models is to provide future studies with different choices including easy and simple equations, as well as slightly more complicated but more accurate models.

Dual energy X-ray absorptiometry measurements

Participants' whole and regional body muscle mass were measured by fan-beam dual energy x-ray absorptiometry (DXA; QDR 4500 A, Hologic, Inc., Waltham, MA). Procedures and validation were introduced in previous studies.[18,19] Measurement and analyses were conducted according to the standard analysis protocol recommended by the Hologic user manual. ASM was calculated as the sum of skeletal muscle mass from the arms and legs.[3]

Anthropometric measurements

Participants' body weight, height, limb circumferences (upper arm, thigh, and calf), waist circumference, and skinfold thicknesses (triceps, thigh, and calf) were measured by trained testers. All the measurements were conducted on the right side of the body. The upper limb length (ULL) was measured from the tip of the acromion to the tip of the middle finger. Thigh length (TL) was measured from the inguinal ligament to the proximal edge of the patella. Calf length (CL) was measured from the proximal end of the medial border of the tibia to the tip of the medial malleolus. Triceps skinfold thickness was measured at midway between the lateral projection of the acromion process of the scapular and the inferior margin of the olecranon process of the ulna. The thigh skinfold site was located in the midline of the anterior aspect of the thigh, midway between the inguinal crease and the proximal border of the patella. Upper arm and thigh circumference were measured via measuring tape horizontally around at the same level as the triceps and thigh skinfolds. Calf circumference was measured by a measuring tape horizontally around at the level of the maximum circumference. The calf skinfold was measured at the point on the medial surface of the calf, at the same level as the calf circumference.

The details of the measurement were presented in the Anthropometric Reference Standardization Manual.[20] Following the methods applied in the previous studies,[15,16] limb circumferences (C_{limb}) were corrected for subcutaneous adipose tissue. As the data (S) obtained from skinfold caliper is twice the adipose tissue thickness, the corrected limb muscle circumference (C_m) could be calculated as $C_m = C_{limb} - \pi S$. In addition, as appendicular circumferences are unidimensional and muscle mass is 3-dimensional, C_m was squared and multiplied by height or limb length to convert to a 3-dimensional measure.[14,16]

Statistical analysis

Descriptive statistics (means and SDs) were used to describe key clinical and demographic characteristics. Based on the data from the MD group, multiple linear regression was applied to develop a limb-length-circumference model, a height-circumference model, and a height-weight model with ASM, using DXA-measured ASM as dependent variable and anthropometric variables as independent variables. For the limb-length-circumference model and height-circumference model, square of corrected limb circumferences multiplied by height (Height×CAG^2, Height×CTG^2, Height×CCG^2) and square of corrected limb circumferences multiplied by limb length (ULL×

Table 1. Participants' physical characteristics and body composition measurements

	Men (n=354)	Women (n=429)	p [§]
Age (y)	39.3 (14.5) [†]	41.1 (14.1)	ns
Weight (kg)	69.7 (11.9)	56.8 (11.9)	<0.001
Height (cm)	171 (6.2)	158 (5.9)	<0.001
Body mass index (BMI) (kg/m^2)	23.9 (3.7)	22.7 (4.5)	<0.001
Limb length (cm)			
Upper limb	73.9 (3.5)	67.0 (5.7)	<0.001
Thigh	50.0 (5.1)	47.0 (4.2)	<0.05
Calf	37.3 (6.3)	34.0 (3.9)	<0.001
Circumference (cm)			
Upper Arm	28.5 (3.5)	26.0 (5.4)	<0.001
Thigh	53.9 (6.3)	52.8 (6.0)	<0.001
Calf	36.8 (3.1)	34.3 (4.0)	<0.001
Skinfold (mm)			
Triceps	14.2 (7.6)	24.0 (8.9)	<0.001
Thigh	21.0 (11.4)	32.0 (11.0)	<0.001
Calf	12.8 (9.1)	19.3 (9.3)	<0.001
Corrected circumference (cm)			
Corrected arm girth (CAG)	24.0 (3.3)	18.4 (4.7)	<0.001
Corrected thigh girth (CTG)	47.3 (6.6)	42.7 (5.3)	<0.001
Corrected calf girth (CCG)	32.8 (3.5)	28.3 (3.9)	<0.001
Appendicular skeletal muscle mass (ASM)	23.4 (3.4)	15.5 (2.5)	<0.001

[†]: Mean (standard deviation)

[§]: Independent t-test was applied to determine the difference between men and women

CAG^2, $TL×CTG^2$, $CL×CCG^2$) were entered directly into the models. Other anthropometric variables were selected by a stepwise procedure using entry criterion of $p<0.05$. The linear coefficient of determination (R^2) was calculated to determine the quality of the prediction models. The developed regression models were then cross-validated using the data from the CV group. Paired t-tests were performed to determine the difference between the ASM estimated by the predication equation and the DXA-measured ASM. Estimated ASM was correlated with DXA-measured ASM and a linear regression was conducted using estimated ASM to predict DXA-measured ASM.

RESULTS

Descriptive characteristics of the study population were presented in Table 1. Data from 354 men and 429 women were finally included in the data analysis. The ASM for Chinese men and women were 23.4± 3.4 kg and 15.5±2.5 kg respectively. Compared with women, men had significant larger arm, thigh and calf circumference, and thinner skinfold at triceps, thigh and calf. Correlation coefficients between ASM and the anthropometric predictors ranged from 0.32 to 0.84, after age was controlled (Table 2). The best predictors for ASM were the square of corrected upper arm circumference multiplied by upper limb length.

Based on the data from the MD group, limb-length-circumference, height-circumference and height-weight models were established. The prediction models were presented in Table 3. The Limb-length-circumference model established in the current study had a high R^2 (0.93) and low SEE (1.33 kg). Satisfactory results were also found in height-circumference model (R^2=0.92, SEE=1.44 kg) and height-weight model (R^2=0.90, SEE=1.63 kg).

Data from the CV group were applied to cross-validate the established equations. The results of the paired t-test showed that there were no significant differences between measured ASM by DXA and estimated ASM by the three models (Table 3). The correlations coefficients between measured and predicted ASM ranged from 0.941 to 0.951. The results of regression showed that predicted ASM could explain 89% to 91% of the variance of the DXA-measured ASM (Figure 1).

Table 2. Correlation coefficients between anthropometric measures and ASM

	r	Partial r †
Age (y)	-0.15	-
Weight (kg)	0.79	0.82
Height (cm)	0.79	0.79
Body mass index (BMI) (kg/m^2)	0.47	0.54
Upper limb length (ULL) (cm)	0.63	0.62
Thigh length (TL) (cm)	0.34	0.32
Calf length (SL) (cm)	0.36	0.35
Upper arm circumference (cm)	0.47	0.51
Thigh circumference (cm)	0.44	0.43
Calf circumference (cm)	0.63	0.63
Corrected arm girth (CAG)	0.60	0.62
Corrected thigh girth (CTG)	0.58	0.57
Corrected calf girth (CCG)	0.63	0.63
$Height×CAG^2$	0.80	0.82
$Height×CTG^2$	0.75	0.75
$Height×CCG^2$	0.76	0.77
$ULL×CAG^2$	0.83	0.84
$TL×CTG^2$	0.77	0.77
$CL×CCG^2$	0.78	0.78

†: Age was controlled for

DISCUSSION

Although MRI, CT and DXA were proven to be valid and reliable instruments to evaluate skeletal muscle mass,[7,8] it is not feasible to apply these expensive and unportable equipments in epidemiological studies with large samples, especially in developing countries. To our knowledge, this could be the first study to develop ASM prediction equations based on anthropometric measures for the Chinese population. In the current study, using DXA-measured ASM as reference, three estimation models were established and cross-validated in a large Chinese study population. The equations may facilitate the estimation of ASM in the Chinese in both research and clinical settings.

Several prediction models for skeletal muscle mass, using three-dimensional quantities (squared corrected appendicular circumferences multiplied by height) as predictors, were reported to be valuable tools for muscle mass estimation.[14-16] The R^2 of these prediction models ranged from 0.86 to 0.96, and SEE is about 1.5kg-2.0kg. Similar to previous studies, a height-circumference model

Table 3. The development and cross-validation of the prediction models for ASM based on the Chinese population

Models	Predication model development †				Cross-validation §		
	Equation ‡	R^2	Adjusted R^2	SEE	Difference Mean (SD)	paired t-test	r
Limb-length-circumference	$= 0.000123×ULL×CAG^2 + 0.00002739×TL×CTG^2 + 0.0000269×CL×CCG^2 – 3.11×gender + 0.128×weight + 0.082×height – 0.029×age – 1.769$	0.93	0.93	1.33	-0.023 (1.47)	0.753	0.951
Height-circumference	$= height×(0.001509×CAG^2 + 0.0008555×CTG^2 + 0.0007709×CCG^2) – 4.044×gender + 0.149×weight – 0.038×age + 12.246$	0.92	0.92	1.44	0.013 (1.55)	0.870	0.946
Height-weight	$= 0.193 × weight + 0.107 × height – 4.157 × gender – 0.037 × age – 2.631$	0.90	0.90	1.63	-0.025 (1.63)	0.761	0.941

ULL: Upper limb length; TL: Thigh length; CL: Calf length; CAG: Corrected Arm Girth; CTG: Corrected Thigh Girth; CCG: Corrected Calf Girth

† : Predication models were developed based on data from the MD group.

§: the estimated ASM by equations were compared with the measured ASM by DXA based on data from the CV group.

‡: weight in kg, Height in m, limb-length in cm, circumferences in cm, age in year, gender:1 for men and 2 for women

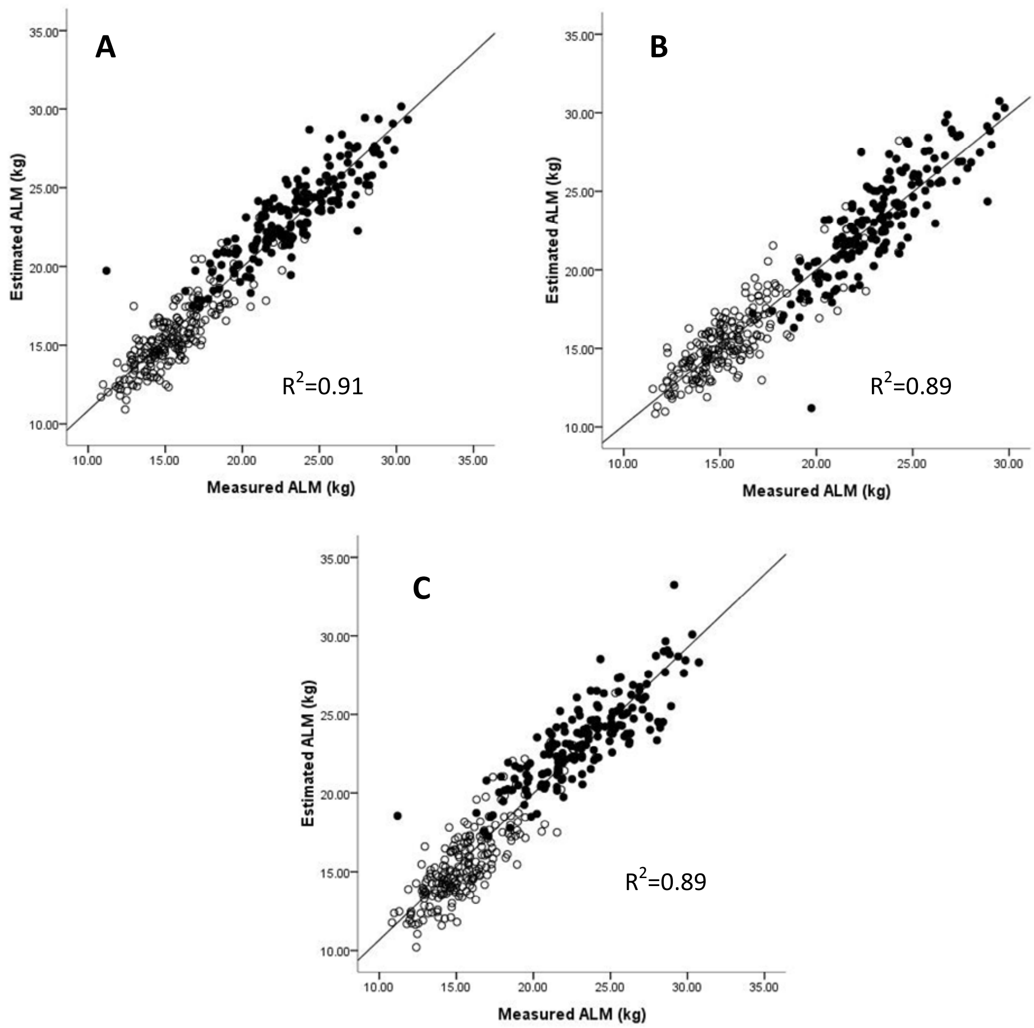

Figure 1. ASM predicted by the limb-length-circumference model (A), the height-circumference model (B), and the height-weight model versus ASM measured by DXA in healthy men (●) and women (○).

was developed in the current study. The R^2 of the current prediction model ranged from 0.90 to 0.93, and SEE is around 1.5 kg. The satisfactory results of regression and cross-validation also indicated that this model could provide accurate estimations of ASM. As ASM is calculated as the sum of lean mass in the arms and legs, it was assumed that square of skinfold-corrected limb circumferences multiplied by the limb length (eg. ULL×CAG^2) should have greater prediction power to estimate ASM than the square of skinfold-corrected limb circumferences multiplied by height (e.g. height×CAG^2). The results of the present study also confirmed that ULL×CAG^2 had higher correlation with DXA-measured ASM than height×CAG^2. Limb-length-circumference model was also found to have higher accuracy than the height-circumference model. However, for the limb-length-circumference model and height-circumference model, data on limb length, skinfold thickness and limb circumferences are needed, which are not always collected in some epidemiological studies. Therefore, a simple prediction equation, height-weight model was developed, in which only body weight, height, gender and age was needed for the estimation of ASM. Although the height-weight model is not as accurate as the other two models, data from this study still suggested that the height-weight model is a practical method of quantifying ASM.

In general, based on data from Chinese adults, three prediction models for ASM were developed and cross-validated in the current study. The results suggested that the developed equations had satisfactory prediction qualities, and could be applied as a practical method of quantifying ASM for Chinese adults, although prospective validation studies are still needed to determine the validity of the prediction models.

AUTHOR DISCLOSURES

No conflicts of interest.

REFERENCES

1. Goodpaster BH, Park SW, Harris TB, Kritchevsky SB, Nevitt M, Schwartz AV, Simonsick EM, Tylavsky FA, Visser M, Newman AB. The loss of skeletal muscle strength, mass, and quality in older adults: The health, aging and body composition study. J Gerontol A Biol Sci Med Sci. 2006; 61:1059-64.
2. Visser M, Goodpaster BH, Kritchevsky SB, Newman AB, Nevitt M, Rubin SM, Simonsick EM, Harris TB. Muscle mass, muscle strength, and muscle fat infiltration as predictors of incident mobility limitations in well-functioning older persons. J Gerontol A Biol Sci Med Sci. 2005;60:324-33.
3. Delmonico MJ, Harris TB, Lee JS, Visser M, Nevitt M, Kritchevsky SB, Tylavsky FA, Newman AB. Alternative definitions of sarcopenia, lower extremity performance, and

functional impairment with aging in older men and women. J Am Geriatr Soc. 2007;55:769-74.
4. Fleg JL, Lakatta EG. Role of muscle loss in the age-associated reduction in VO2 max. J Appl Physiol. 1988;65: 1147-51.
5. Lauretani F, Russo CR, Bandinelli S, Bartali B, Cavazzini C, Di Iorio A, Corsi AM, Rantanen T, Guralnik JM, Ferrucci L. Age-associated changes in skeletal muscles and their effect on mobility: an operational diagnosis of sarcopenia. J Appl Physiol. 2003;95:1851-60.
6. Janssen I, Shepard DS, Katzmarzyk PT, Roubenoff R. The healthcare costs of sarcopenia in the United States. J Am Geriatr Soc. 2004;52:80-5.
7. Mitsiopoulos N, Baumgartner RN, Heymsfield SB, Lyons W, Gallagher D, Ross R. Cadaver validation of skeletal muscle measurement by magnetic resonance imaging and computerized tomography. J Appl Physiol. 1998;85:115-22.
8. Chen Z, Wang Z, Lohman T, Heymsfield SB, Outwater E, Nicholas JS et al. Dual-energy X-ray absorptiometry is a valid tool for assessing skeletal muscle mass in older women. J Nutr. 2007;137:2775-80.
9. Kim J, Wang Z, Heymsfield SB, Baumgartner RN, Gallagher D. Total-body skeletal muscle mass: estimation by a new dual-energy X-ray absorptiometry method. Am J Clin Nutr. 2002;76:378-83.
10. 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.
11. Lau EMC, Lynn HSH, Woo JW, Kwok TCY, Melton LJI. Prevalence of and risk factors for sarcopenia in elderly Chinese men and women. J Gerontol A Biol Sci Med Sci. 2005;60:213-6.
12. Janssen I, Heymsfield SB, Baumgartner RN, Ross R. Estimation of skeletal muscle mass by bioelectrical impedance analysis. J Appl Physiol. 2000;89:465-71.
13. Jackson AS, Pollock ML, Graves JE, Mahar MT. Reliability and validity of bioelectrical impedance in determining body composition. J Appl Physiol. 1988;64:529-34.
14. Doupe MB, Martin AD, Searle MS, Kriellaars DJ, Giesbrecht GG. A new formula for population-based estimation of whole body muscle mass in males. Can J Appl Physiol. 1997;22:598-608.
15. Lee RC, Wang ZM, Heo M, Ross R, Janssen I, Heymsfield SB. Total-body skeletal muscle mass: development and cross-validation of anthropometric prediction models. Am J Clin Nutr. 2000;72:796-803.
16. Martin AP, Spenst LF, Drinkwater DT, Clarys JP. Anthropometric estimation of muscle mass in men. Med Sci Sports Exerc. 1990;22:729-33.
17. Ortiz O, Russell M, Daley T, Baumgartner RN, Waki M, Lichtman S, Wang J, Pierson RN Jr, Heymsfield SB. Differences in skeletal muscle and bone mineral mass between black and white females and their relevance to estimates of body composition. Am J Clin Nutr. 1992;55:8-13.
18. Salamone LM, Fuerst T, Visser M, Kern M, Lang T, Dockrell M, Cauley JA, Nevitt M, Tylavsky F, Lohman TG. Measurement of fat mass using DEXA: a validation study in elderly adults. J Appl Physiol. 2000;89:345-52.
19. van der Ploeg GE, Withers RT, Laforgia J. Percent body fat via DEXA: comparison with a four-compartment model. J Appl Physiol. 2003;94:499-506.
20. Lohman TG, Roche AF, Martorell R. Anthropometric Reference Standardization Manual. Champaign, IL: Human Kinetics; 1988.

Original Article

Anthropometric equation for estimation of appendicular skeletal muscle mass in Chinese adults

Xu Wen PhD[1], Mei Wang MEd[2], Chong-Min Jiang PhD[2], Yi-Min Zhang PhD[3]

[1]*Department of Physical Education, Zhejiang University, Hangzhou, China*
[2]*China Institute of Sports Science, Beijing, China*
[3]*Beijing Sport University, Beijing, China*

中国成年人四肢骨骼肌含量的体位方程式

本研究的目的是发展和验证中国成年人四肢骨骼肌含量的预测方程式。研究在中国济南、广州、西安、成都四地招募 763 名 18-69 岁成年人，其中男性 345 名、女性 418 名。通过双能 X 光吸收法测量受试者的四肢骨骼肌含量。由经培训的测量员的测量受试者的体重、身高、上臂围、大腿围、小腿围、腰围、皮褶厚度（肱三头肌、大腿、小腿）。将受试者随机分成建模组和验证组，利用建模组数据建立四肢骨骼肌含量预测方程，然后采用验证组数据检验预测方程的效果。研究结果显示，本研究建立的方程具有较好的预测效果，可以应用于中国成年人四肢骨骼肌含量的预测。

关键词：骨骼肌质量、预测模式、身体组成、体位测量、皮褶厚度