Journal of Parenteral and Enteral Nutrition
Volume 00 Number 0
May 2019 1–10

DOI: 10.1002/jpen.1605
wileyonlinelibrary.com
WILEY

New Prediction Equations to Estimate Appendicular Skeletal Muscle Mass Using Calf Circumference: Results From NHANES 1999–2006

Leonardo Pozza Santos, PhD[1,*]; Maria Cristina Gonzalez, MD, PhD[2,3,*]; Silvana Paiva Orlandi, PhD[4]; Renata Moraes Bielemann, PhD[4,5]; Thiago G. Barbosa-Silva, PhD[5]; Steven B. Heymsfield, MD[3]; and On behalf of the COCONUT Study Group

Abstract

Background: Low appendicular skeletal muscle mass (ASM) is associated with negative outcomes, but its assessment requires proper limb muscle evaluation. We aimed to verify how anthropometric circumferences are correlated to ASM and to develop new prediction equations based on calf circumference and other anthropometric measures, using dual-energy X-ray absorptiometry (DEXA) as the reference method. *Methods:* DEXA and anthropometric information from 15,293 adults surveyed in the 1999–2006 NHANES were evaluated. ASM was defined by the sum of the lean soft tissue from the limbs. Anthropometric data included BMI and calf, arm, thigh, and waist circumferences. Correlations were assessed by Pearson's correlation, and multivariable linear regression produced 4 different ASM prediction equations. The concordance and the overall 95% limits of agreement between measured and estimated ASM were assessed using Lin's coefficient and Bland-Altman's approach. *Results:* Calf and thigh circumferences were highly correlated with ASM, independent of age and ethnicity. Among the models, the best performance came from the equation constituted solely by calf circumference, sex, race, and age as independent variables, which was able to explain almost 90% of the DEXA-measured ASM variation. The inclusion of different anthropometric parameters in the model increased collinearity without improving estimates. Concordance between the four developed equations and DEXA-measured ASM was high (Lin's concordance coefficient >0.90). *Conclusion:* Despite the good performance of the four developed equations in predicting ASM, the best results came from the equation constituted only by calf circumference, sex, race, and age. This equation allows satisfactory ASM estimation from a single anthropometric measurement. (*JPEN J Parenter Enteral Nutr.* 2019;00:1–10)

Keywords

body composition; nutrition surveys; sarcopenia

Clinical Relevancy Statement

Low muscle mass seems to be the mediator of several complications associated with malnutrition. It is also important in the sarcopenia diagnosis in elderly subjects, and its diagnosis requires proper muscle quantity evaluation, which is mainly based on high-cost, time-consuming, or health facility–restricted methods. In this study, we showed that

From the [1]Nutrition College, Federal University of Pampa, Bagé, Brazil; [2]Postgraduate Program in Health and Behavior, Catholic University of Pelotas, Pelotas, Brazil; [3]Pennington Biomedical Research Center, Louisiana State University, Baton Rouge, Louisiana, USA; [4]Nutrition College, Federal University of Pelotas, Pelotas, Brazil; and the [5]Postgraduate Program in Health and Behavior and in Epidemiology, Federal University of Pelotas, Pelotas, Brazil.

Financial disclosure: This study was one of the Harry M Vars Award candidates at ASPEN19. LP Santos' presence at ASPEN19 was supported by the Fundação de Amparo a Pesquisa do estado do Rio Grande do Sul, under the protocol no 18/2551-0001067-7.

Conflicts of interest: None declared.

*Leonardo Pozza Santos and Maria Cristina Gonzalez share first authorship.

[This article was modified on May 16, 2019, after initial online publication to add the second author's ORCID ID and to note the shared first authorship.]

Received for publication January 16, 2019; accepted for publication April 22, 2019.

This article originally appeared online on xxxx 0, 2019.

Corresponding Author:
Maria Cristina Gonzalez, PhD, Postgraduate Program in Health and Behavior, Catholic University of Pelotas, RS, Ver. Ariano R. de Carvalho, 304 CEP 96055–800 Pelotas, RS, Brazil.
Email: cristinagbs@hotmail.com

calf circumference appears to represent an adequate predictor of appendicular skeletal muscle mass (ASM), since it is highly correlated with dual-energy X-ray absorptiometry–measured ASM, independent of age and ethnicity. In addition, the prediction equation based on calf circumference, sex, ethnicity, and age satisfactorily estimated ASM. These results are important for the clinical and research contexts, since it allows us to estimate ASM using a single, easy, low-cost, and universally available anthropometric measure.

Introduction

Elderly populations are increasing in both high-income and middle-income countries. The World Health Organization estimates that by 2050 approximately 20% of the worldwide population will be constituted by subjects over 65 years old, outnumbering children under 5 for the first time in human history.[1] In the United States, this scenario is not different; the U.S. Census Bureau's National Population Projection expects around 80 million 65-or-older United States citizens in 2035. By then, the proportion of people under 18 years old in the United States population should be surpassed by the elderly.[2]

As a consequence of this population-aging process, clinicians and public health practitioners are increasingly turning their attentions to elderly-related outcomes such as sarcopenia, malnutrition, or cachexia, all of them associated with low muscle mass. Among those, special consideration should be given to sarcopenia, an age-related syndrome characterized by progressive loss of muscle mass and function.[3-7] Sarcopenia has personal and financial costs and has been associated with several negative outcomes in older adults, such as falls, fractures and mobility disorders, cognitive impairments, and mortality.[6,7]

Diagnosing sarcopenia requires proper muscle quantity evaluation, and in this context, appendicular skeletal muscle mass (ASM) is frequently the preferred compartment. However, estimating muscle mass can be a troublesome task, one that usually requires the use of high-cost, time-consuming, or health facility–restricted methods such as computed tomography and dual-energy X-ray absorptiometry (DEXA).[8,9] Alternatively, over the last years, ASM prediction equations based on bioelectrical impedance analysis (BIA) have been proposed.[10-14] However, BIA also has limitations of its own, particularly in older subjects and clinical settings.[15]

More recently, low muscle mass was included as an important criterion for the malnutrition definition (Global Leadership Initiative on Malnutrition).[16] This inclusion arose questions about how muscle mass could be assessed not only solely in older subjects but also in the general population at any place where malnutrition assessment is necessary. Given the low availability of muscle evaluation tools in primary healthcare units and the limited resource environments, researchers keep looking for easier and less expensive ways to estimate ASM. In this fashion, anthropometric measurements are frequently proposed as indirect markers of ASM, a scenario in which calf circumference might play a somehow important role.[17-21] Calf circumference is an easy, low-cost, and universally available anthropometric measure, whose correlation with ASM has been previously reported to range from good to moderate.[17-19] Nevertheless, such studies were mainly based on elderly samples, and the extent to which calf circumference could represent an adequate predictor of ASM in large samples with different age and ethnic groups remains, at the moment, unknown.

Considering the aspects mentioned above, our main objective in this study was to evaluate the performance of calf circumference and additional anthropometric measurements as ASM predictors in a large sample of adults from the National Health and Nutrition Examination Survey (NHANES). Additionally, using DEXA as the reference method, we intended to develop new ASM prediction equations based on easily available demographic and anthropometric data.

Materials and Methods

Study Participants

This study used data from NHANES, a cross-sectional study periodically conducted by the U.S. National Center for Health Statistics to assess health and nutrition status of a nationally representative sample of United States children and adults. The survey uses a multistage probability sampling design for participant selection, which allows extrapolation of the results for the whole United States population.

NHANES began in the 1960s, and different approaches have been employed throughout the years. Since 1999, however, NHANES annually surveys around 5000 participants from different counties across the United States regarding socioeconomic, demographic, nutrition, and health-related characteristics. More information about NHANES can be assessed at https://www.cdc.gov/nchs/nhanes/index.htm.

In this study, we used data from the 1999 to the 2006 NHANES editions. Our analysis was restricted to 15,239 adults (older than 18 years) with available information on DEXA body composition assessments and anthropometric circumferences (namely calf, arm, and thigh circumferences).

DEXA Assessments

Body composition assessment by DEXA was performed using a Hologic QDR 4500A fan beam X-ray bone densitometer (Hologic Inc., and Hologic Discovery software, version 12.1) at the Mobile Examination Center. Prior to the exam, participants were asked to remove earrings, piercings, and any other metallic objects. Subjects stood in the supine position over the device's table, with arms extended along the body, barefoot, and feet wrapped by Velcro straps. Whole body scans took about 3 minutes. Participants were restrained from DEXA assessments if their weight or height exceeded 136 kg (300 lb) or 1.96 m (6 ft 5 in), respectively, or if they were submitted to contrast-based radiological or nuclear medicine examinations in the prior 72 hours. The exams were conducted by trained technicians who also periodically assessed the quality of the exams and calibrated the device according to NHANES protocols. Further details can be assessed in the NHANES procedures manual.[22-25]

Appendicular lean soft tissue (ALST) can be assessed by the sum of the lean soft tissue mass from the 4 limbs obtained from whole body DEXA scans. ALST is 85% constituted by muscle.[26] Even though the terms represent slightly different compartments, ALST is usually used as a good surrogate for ASM, and for this reason, both terms are often used as synonyms. Therefore, in this study (and from here on throughout the text), the DEXA-measured ALST (the bone and fat-free appendicular mass) will be referred as ASM.

Anthropometric Measures

Anthropometric measures were also collected at the Mobile Examination Center by properly trained study personnel. Available data of calf, arm, thigh, and waist circumferences; weight; and height were used in the current study.

Calf circumference was measured with the participants seated, at the point of maximum circumference on a plane perpendicular to the long axis of the right calf. Patients stayed upright during the measurement of the arm circumference, with shoulders relaxed, and the right arm hanging loosely. The circumference was measured perpendicularly to the long axis of the right upper arm, at the midpoint between the acromion and the olecranon. For the measurement of the thigh circumference, participants were asked to stand up and shift the body weight to the left leg, keeping the right knee slightly flexed and both feet flat on the floor. Thigh circumference was then measured at the right leg in the midpoint between the iliac crest and the knee, perpendicularly to the long axis of the limb. Finally, waist circumference was measured on a horizontal plane around the trunk, just above the ilium, at the end of normal expiration. All circumferences were obtained using an inextensible steel measuring tape, and values were rounded to the nearest 0.1 cm.

Participants' body mass index (BMI) was calculated from the available weight and height data. Weight was measured using a Toledo digital scale, with participants wearing nothing but underwear, foam slippers, and disposable paper gowns. Weight was registered in pounds and converted to kilograms afterward. Height was measured using a fixed stadiometer with a vertical backboard and a movable headboard. Participants stood up straight, with the head aligned to the Frankfort horizontal plane and without any hair ornaments. BMI was then calculated by dividing the weight (kg) by the squared height (m^2), and according to each participants' BMI status, individuals were classified as normal (18.5–24.9 kg/m^2), overweight (25.0–29.9 kg/m^2), or obese ($\geq$30 kg/m^2). Further information concerning anthropometric measurements can be obtained in the NHANES anthropometry manuals.[27-30]

Demographic Characteristics

Socioeconomic and demographic data were collected during the household interviews. The participants' sex, age, and self-reported ethnicity were adopted in the current study as possible ASM predictors.

Statistical Analysis

To identify the best ASM predictors among the available circumferences (calf, arm, and thigh), we assessed their correlations using Pearson's correlation coefficients. In this analysis, subjects were stratified by sex, BMI status, ethnicity, and age groups, and the obtained results were classified as negligible (0.0–0.3), low (>0.3–0.5), moderate (>0.5–0.7), high (>0.7–0.9), and very high (>0.9–1.0).[31]

Four prediction models were proposed from the available dataset and subsequently evaluated through multivariable linear regression analysis: (1) Calf circumference, sex, ethnicity, and age as independent variables; (2) variables included in Equation 1 + arm and thigh circumferences; (3) variables included in Equation 2 + BMI; and (4) variables included in Equation 3 + waist circumference.

To increase the robustness of the regression estimates, the model diagnosis was performed. Outlier residuals and influential cases were excluded from all models. We classified standardized residuals as outliers if they stayed below −2 or above 2 standard deviations. Influential cases were detected by Cook's distance as follows: 4/N; where N is the sample population in the tested model. All individuals who stood above the result of Cook's distance calculation were considered influential cases and excluded from the analysis.[32]

Lin's concordance correlation coefficient and Bland-Altman's approach were used to assess the concordance and the overall 95% limits of agreement between DEXA-measured and estimated ASM. The equations' performance in different age groups (18–19, 20–39, 40–59, ≥60 years) and ethnicities (white, African American, Mexican American, and other) was also evaluated.

Table 1. Demographic Characteristics and BMI Status of Individuals Surveyed in NHANES 1999–2006 (N = 15,239).

Demographic Characteristics and BMI Status	N (%)
Sex	
Male	7810 (51.1)
Female	7483 (48.9)
Age, yr	
<20	1793 (11.7)
20–39	4720 (30.9)
40–59	4513 (29.5)
≥60	4267 (27.9)
Race	
White	7183 (47.0)
African American	3170 (20.7)
Mexican American	3702 (24.2)
Other	1238 (8.1)
BMI status, kg/m^2	
Normal	5507 (36.3)
Overweight	5532 (35.3)
Obese	4306 (28.4)

BMI, body mass index; NHANES, National Health and Nutrition Examination Survey.

Results

Data from 15,293 1999–2006 NHANES adult participants were available, and therefore such subjects constituted the study sample. Sex was evenly distributed (51.1% males). Mean age was 45.2 years (±19.4), and subjects aged 60 or older represented approximately one-third of the sample. Regarding ethnicity, almost half of the sample was composed by non-Hispanic whites. Concerning BMI, about two-thirds of the participants were classified as overweight or obese (Table 1).

Table 2 shows DEXA-measured ASM and anthropometric circumferences according to sex, ethnicity, and age. Men presented higher ASM as well as higher calf, arm, and waist circumferences. There was no difference in thigh circumference among sexes. African American subjects presented higher ASM and higher calf, arm, and thigh circumferences. Elderly people, opposingly, had the lowest amount of ASM as well as lower calf and thigh circumferences but higher waist circumference.

Pearson's correlation coefficients showed that calf, arm, and thigh circumferences were highly correlated with DEXA-measured ASM in both men and women (correlation coefficients >0.7 for all circumferences, data not shown in tables and figures). Stratification by BMI status, ethnicity, and age (Figure 1) evidenced moderate correlations between ASM and calf circumference among all BMI subgroups, with values ranging from 0.61 (overweight women) to 0.70 (underweight men). High correlations were observed among all ethnic subgroups, with values ranging from 0.79 (non-Hispanic black women) to 0.83 (non-Hispanic white men and women). Finally, high correlations were also found among all age subgroups, varying from 0.74 (≥60-year-old women) to 0.85 (<20-year-old women). Correlation coefficients for thigh circumference were similar to the ones observed for calf circumference, whereas the coefficients found for arm circumference were lower (Figure 1).

Coefficients and estimates from the developed equations are displayed in Table 3. After model diagnosis, Equation 1

Table 2. Mean of DEXA and Anthropometric Circumferences Stratified by Gender, Ethnicity and Age (N = 15,239).

Demographic Characteristics	ASM, kg Mean (SD)	Calf Circumference, cm Mean (SD)	Arm Circumference, cm Mean (SD)	Thigh Circumference, cm Mean (SD)	Waist Circumference, cm Mean (SD)
Sex, *P*	<0.001	<0.001	<0.001	0.325	<0.001
Men	25.6 (4.6)	38.3 (3.6)	33.1 (3.9)	52.7 (5.8)	96.5 (13.7)
Women	17.4 (3.7)	37.6 (4.3)	31.6 (5.0)	52.5 (7.3)	92.4 (14.6)
Race, *P*	<0.001	<0.001	<0.001	<0.001	<0.001
White	21.5 (5.8)	38.3 (3.9)	32.2 (4.5)	52.2 (6.2)	95.4 (14.4)
African American	24.2 (6.0)	38.6 (4.2)	33.3 (5.0)	55.5 (7.3)	93.6 (15.4)
Mexican American	20.1 (5.2)	36.9 (3.7)	32.0 (4.1)	51.2 (5.8)	94.5 (13.2)
Other	20.4 (5.7)	37.3 (4.0)	31.6 (4.5)	51.5 (6.6)	91.5 (13.5)
Age, yr, *P*	<0.001	<0.001	<0.001	<0.001	<0.001
<20	22.0 (6.0)	37.4 (4.1)	30.6 (4.7)	52.8 (7.0)	84.8 (13.9)
20–39	22.6 (6.0)	38.4 (4.0)	32.4 (4.7)	53.9 (6.6)	91.2 (13.7)
40–59	22.2 (5.8)	38.7 (3.8)	33.2 (4.4)	53.4 (6.2)	97.0 (13.5)
≥60	19.9 (5.3)	37.0 (3.8)	32.1 (4.3)	50.2 (6.1)	99.6 (12.9)

ASM, DEXA-measured appendicular skeletal muscle mass (sum of the 4 limbs).
Displayed *P*-values from analysis of variance for the differences by sex, ethnicity, and age.ASM, appendicular skeletal muscle mass; DEXA, dual-energy X-ray absorptiometry.

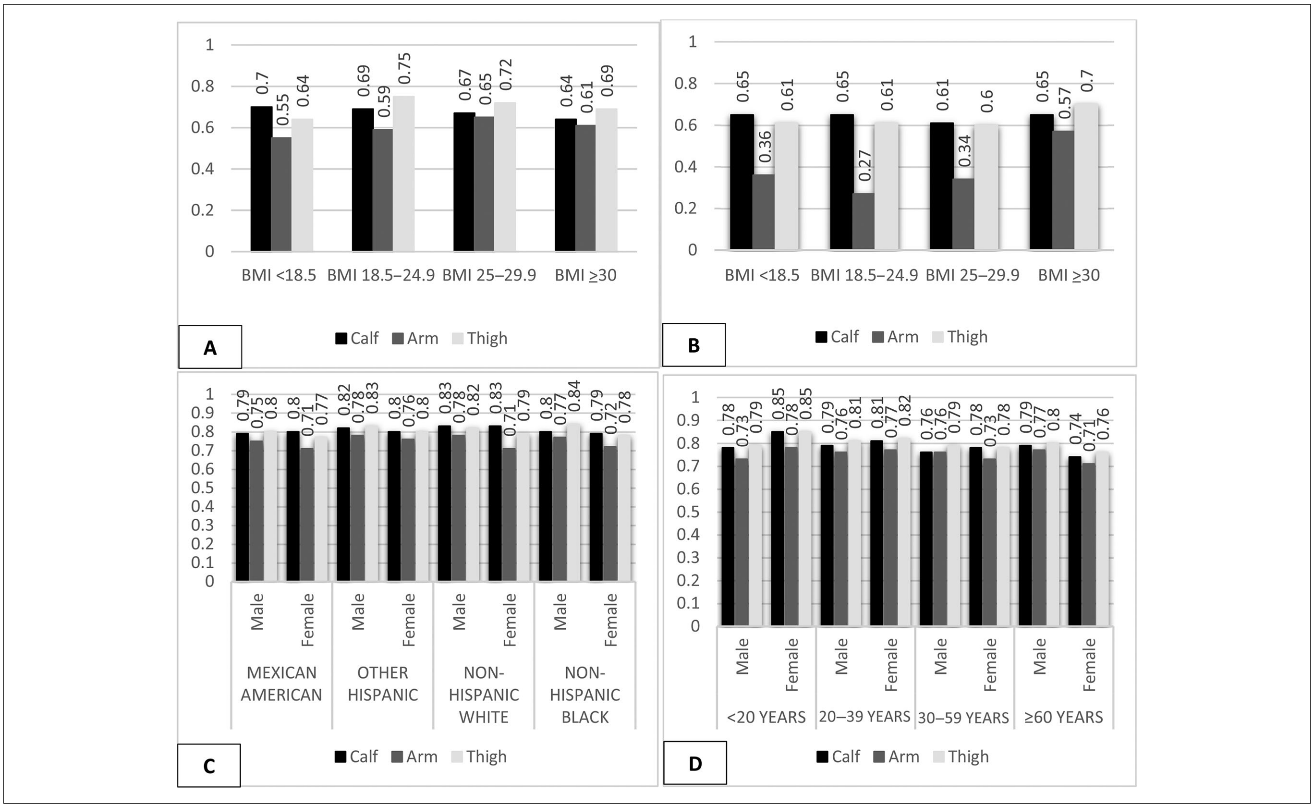

Figure 1. Correlation between dual-energy X-ray absorptiometry–measured appendicular skeletal muscle mass and calf, arm, and thigh circumferences according to BMI status (subgroups of men and women, A and B, respectively), race (C), and age (D). BMI, body mass index.

(calf circumference, sex, ethnicity, and age as independent variables) explained almost 90% of the DEXA-measured ASM variability (adjusted $R^2 = 0.88$; root mean square error = 1.95 kg). Inclusion of the other circumferences and BMI as prediction variables on the remaining equations have neither improved the adjusted R^2 nor significantly decreased the root mean square error. Finally, the inclusion of different anthropometric parameters in the model, particularly BMI and waist circumference in Equations 3 and 4, have only increased collinearity without significantly improving estimates (Table 3).

Bland-Altman analysis (Table 4) illustrates the high concordance found among the prediction equations and DEXA-measured ASM, evidenced by Lin's concordance coefficients over 0.90. Moreover, the average difference between measurements and estimates was lower than 0.08 kg for all equations, with 95% limits of agreement between −4.5 and 4.5 kg. Stratification by sex suggested slightly better predictive performances of the equations among women. Stratification by age and ethnicity, however, had no significant impact on estimates, evidenced by similar performances among strata (Figures 2 and 3).

Discussion

In the current study, calf and thigh circumferences were highly correlated with ASM in all age and ethnic subgroups. These results suggest that calf and thigh circumference might be used as a marker of muscle mass not only in older subjects but also in early and middle-aged adults. Nevertheless, calf circumference might be considered better to be used in older subjects and clinical settings because it is simpler to be collected in these contexts than thigh circumference. Jamaiyah et al[33] have previously reported the reliability in the use of calf circumference in individuals older than 60 years of age.

The use of calf circumference for predicting negative health outcomes in elderly populations has been well described in scientific literature. In 2016, Hsu et al[34] demonstrated that calf circumference is better than BMI to predict emerging care need in a Taiwanese older sample. Easton et al[35] pointed out the association between calf circumference and mortality to be the strongest among anthropometric measurements in a Mexican older sample, in which lower calf circumferences were related to higher mortality hazards.[35] More recently, calf circumference has

Table 3. Coefficients (β) and Estimates for Each Term Included in the Appendicular Skeletal Muscle Mass Equations (N = 15,239).

	Equation 1[a]	Equation 2	Equation 3	Equation 4
Intercept	–10.427	–9.241	–11.886	–13.119
Age, yr	–0.029	–0.035	–0.026	–0.037
Sex				
Female	0	0	0	0
Male	7.523	7.353	7.063	6.780
Ethnicity				
White	0	0	0	0
African American	2.203	1.776	1.730	1.932
Mexican American	–0.540	–0.965	–0.718	–0.662
Other	–0.402	–0.641	–0.524	–0.416
Calf circumference, cm	0.768	0.435	0.467	0.459
Arm circumference, cm	—	0.261	0.358	0.318
Thigh circumference, cm	—	0.069	0.111	0.114
Body mass index, kg/m^2	—	—	–0.155	–0.267
Waist circumference, cm	—	—	—	0.067
Adjusted R^2	0.88	0.90	0.90	0.90
RMSE	1.95	1.79	1.77	1.74
VIF	1.09	2.55	3.52	4.51

[a]Equation 1 → ASM (kg) = −10.427 + (calf circumference × 0.768) − (age × 0.029) + (sex × 7.523) + (white × 0 or black × 2.203 or Mexican American × −0.540 or other × −0.402).
RMSE, root mean square error; VIF, variance inflation factor.

Table 4. Concordance and Limits of Agreement Between DEXA-Measured and Equation-Estimated ASM in the Whole Sample and According to Gender.

Equation	Lin's CCC	Difference (Average)	95% Limits of Agreement
Overall population (N = 15204)			
Equation 1	0.912	0.078	−4.518; 4.674
Equation 2	0.925	0.049	−4.205; 4.303
Equation 3	0.930	0.056	−4.059; 4.172
Equation 4	0.930	0.053	−4.063; 4.170
Men (N = 7760)			
Equation 1	0.783	0.137	−4.908; 5.182
Equation 2	0.820	0.111	−4.526; 4.748
Equation 3	0.836	0.120	−4.335; 4.575
Equation 4	0.833	0.112	−4.377; 4.601
Women (N = 7444)			
Equation 1	0.844	0.017	−4.055; 4.089
Equation 2	0.866	−0.016	−3.825; 3.793
Equation 3	0.870	−0.010	−3.732; 3.713
Equation 4	0.873	−0.009	−3.691; 3.674

ASM, appendicular skeletal muscle mass; CCC, concordance correlation coefficient; DEXA, dual-energy X-ray absorptiometry.

been demonstrated to predict hospital readmission even in younger adults.[36]

Calf circumference is usually found to be a better marker of muscle mass than its anthropometric counterparts. This might be partially explained by a "less biased" association with muscle mass than other body sites, since the calf is generally less affected by localized fat deposits unlike, for instance, the waist or the thigh circumferences. Bonnefoy et al[37] and Barbosa-Silva et al[38] pointed out calf circumference as a good marker for malnutrition in European and Latin American samples. In both studies, the authors proposed a cutoff to define malnutrition: 30.5 cm in the European sample[37] and 34 and 33 cm for Latin American men and women, respectively.[38]

It is interesting to highlight that most of the above-mentioned studies have tested calf circumference against ASM using elderly samples. In our study, we found high correlation between calf circumference and ASM, independent of ethnicity and age. Surprisingly, calf circumference was highly correlated with ASM in both men and women, even in the younger age group (20 years or less), indicating this measure as a good marker of ASM not just in elderly populations.

Additionally, in the current study, not only was calf circumference found to be highly correlated with ASM but also a satisfactory ASM predictor. Even as the only anthropometric measurement among demographic variables, calf circumference contributed to the 90% of ASM's variability. In fact, despite the observed adequate performance presented by the 4 developed equations, we strongly believe that Equation 1 (based solely on calf circumference, age, sex, and ethnicity) might be the main contribution of this study. Being able to accurately estimate ASM (accounting for 90% of its variability) from 3 simple demographic variables and a single anthropometric measurement represents a valuable

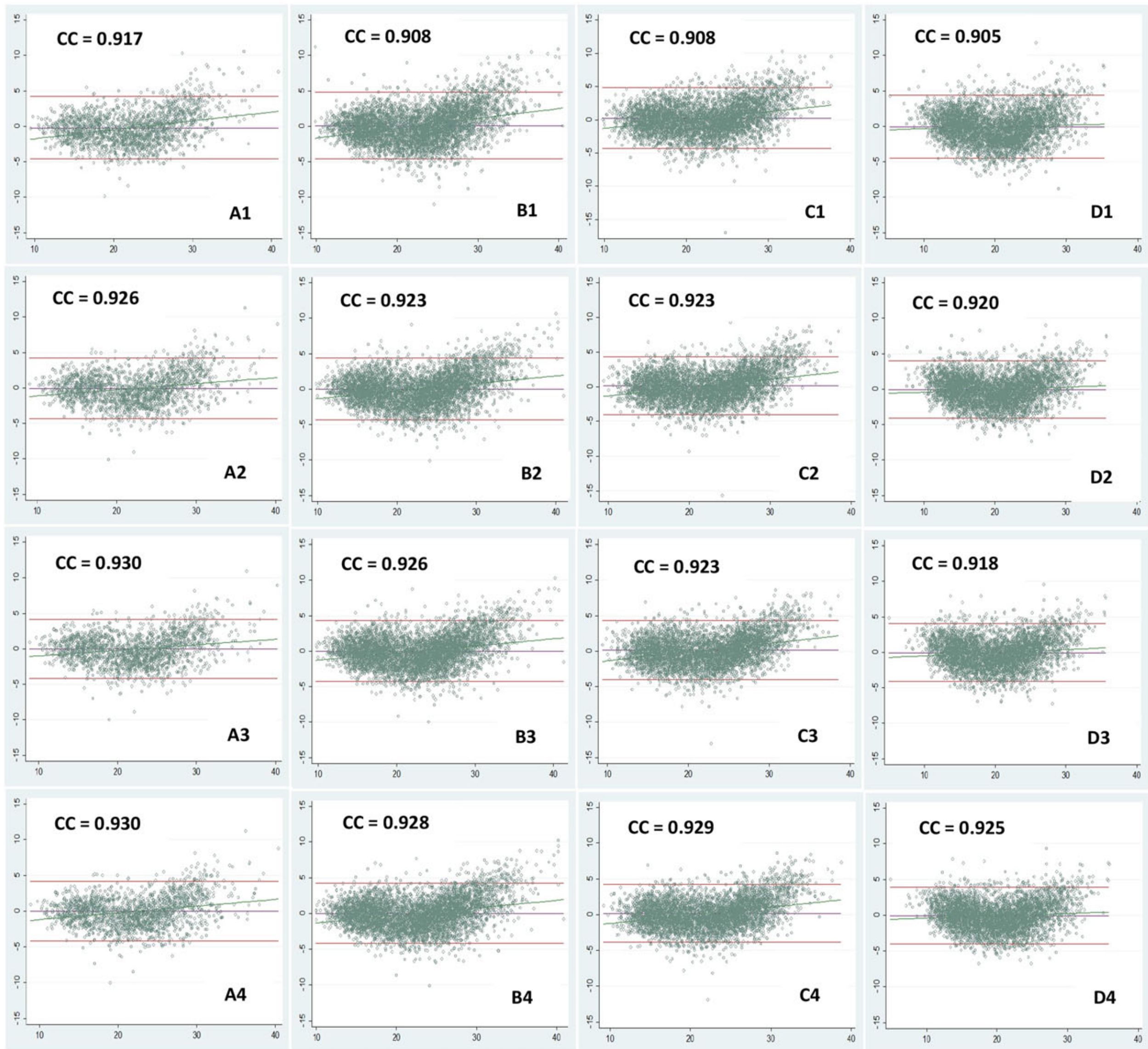

Figure 2. Concordance between dual-energy X-ray absorptiometry–measured and equation-estimated appendicular skeletal muscle mass according to age groups (1, Equation 1; 2, Equation 2; 3, Equation 3; and 4, Equation 4). A, <20 years. B, 20–39 years. C, 40–59 years. D, ≥60 years. CC, concordance coefficient.

(and feasible) option for muscle mass estimation in deprived scenarios. Finally, our equation accurately estimated ASM in all age groups, not only allowing ASM estimation in elderly individuals but also in early and middle adulthood, thus becoming a useful tool to prevent malnutrition, sarcopenia, and cachexia in clinical and public health contexts.

This is not the first study to propose ASM prediction equations based on calf circumference. Two previous studies have already reported similar models.[21,39] Hwang et al[39] proposed an equation based on the evaluation of a ≥50-year-old community-dwelling sample in Taiwan, whereas Wen et al[21] developed their equation from a Chinese population. These equations, however, were based on Asian elderly samples and included further anthropometric parameters such as weight, height, and other circumferences.

Other published equations to estimate ASM are mainly based on BIA.[10-12,40,41] BIA is less expensive and easier than other techniques such as DEXA and ultrasound, for example, but also has some limitations, and its use in clinical routines can be restricted because of several factors related to patient conditions.[15] Moreover, the accuracy of BIA equations to estimate ASM are device-specific and population-specific.[23] Derived equations to estimate ASM based on calf circumference are important because this

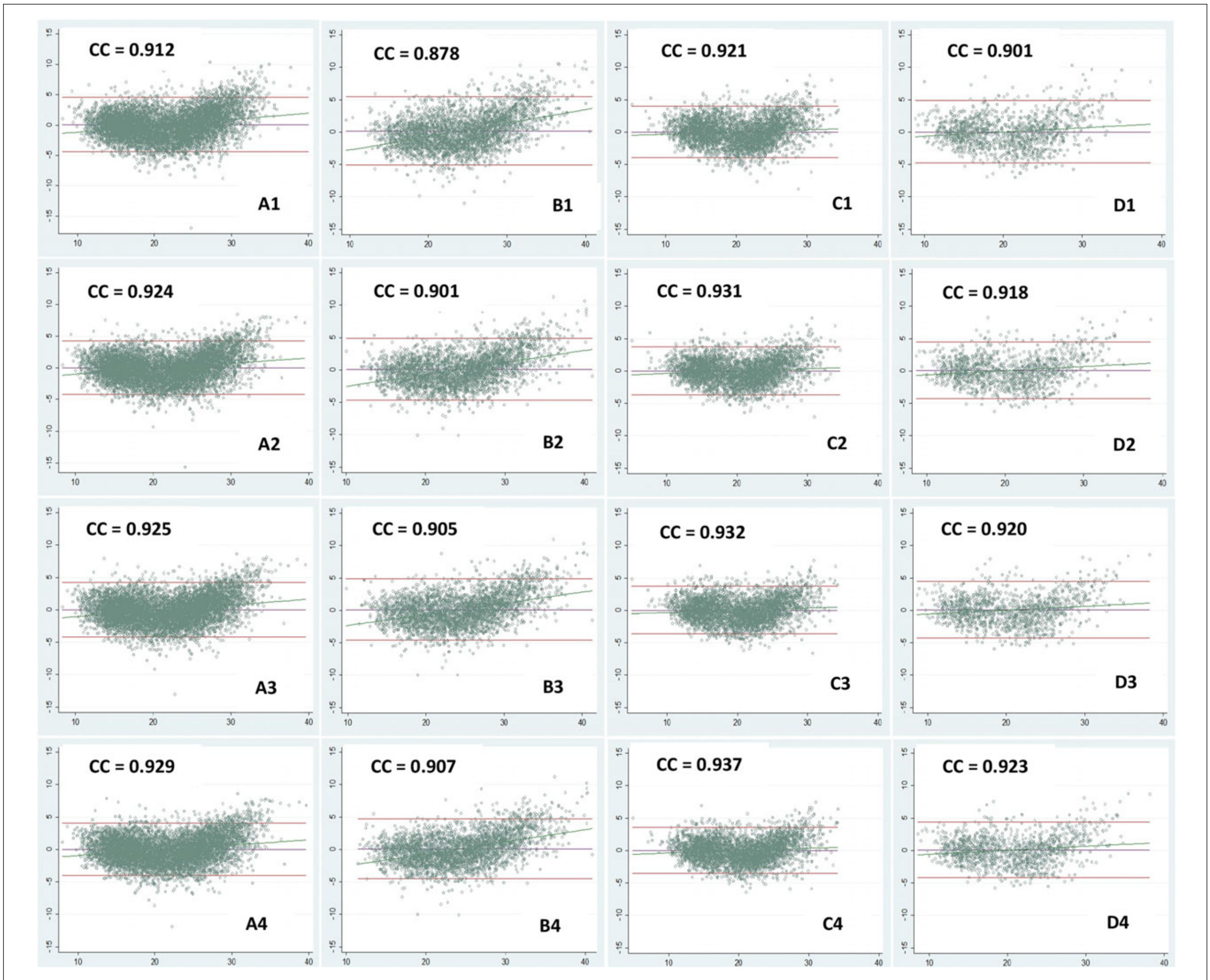

Figure 3. Concordance between dual-energy X-ray absorptiometry–measured and equation-estimated appendicular skeletal muscle mass according to ethnic groups (1, Equation 1; 2, Equation 2; 3, Equation 3; and 4, Equation 4. A, White. B, African American. C, Mexican American. D, Other. CC, concordance coefficient.

measure is easy to collect, even in individuals under critical conditions, such as patients in intensive care units, as long as edema is not present.

The main limitation of the current study might be considered to be the use of DEXA to estimate ASM, particularly in a sample composed by a considerable proportion of older subjects (which may negatively impact the method's accuracy).[26] However, DEXA is accepted by the European Working Group on Sarcopenia in Older People as an adequate tool for muscle mass assessment in elderly subjects.[7] Moreover, despite that the large sample size can be considered one of the study's strengths since it comprised different age and ethnic groups and increased the power of our study, analyses had not taken the NHANES complex survey design into account, not allowing for representativeness of our results for the distribution of sex, age, and ethnicity or reference values for any measurement. The quality of the body composition and anthropometric assessments, based on standardized methods replicated through the different waves of NHANES, is another positive aspect to be considered.

In conclusion, calf circumference showed a good correlation with ASM, and along with sex, ethnicity, and age, it was able to explain almost 90% of the DEXA-measured ASM variability. The proposed equation allows satisfactory ASM estimation from a single anthropometric measurement, which may be useful in clinical and research contexts. Further investigation is needed to evaluate the performance of the proposed equation in different settings.

Statements of Authorship

This study was conducted by all authors. L. P. Santos performed the statistical analyses and drafted the manuscript. M. C. Gonzalez proposed the idea, supervised all the statistical analyses processes, and helped in drafting the manuscript. S. P. Orlandi, R. M. Bielemann, T. G. Barbosa-Silva, and S. B. Heymsfield helped in interpreting results and in drafting the manuscript. M. C. Gonzalez and H. B. Heymsfield contributed to the NHANES data acquisition. All authors read and approved the final version of this manuscript.

References

1. World Health Organization, National Institute on Aging, National Institute on Health. Global Health and Aging. Geneva, Switzerland: World Health Organization; 2011.
2. The United States Census Bureau. Population Projections. The United States Census Bureau; 2017.
3. Evans WJ. What is sarcopenia? *J Gerontol A Biol Sci Med Sci*. 1995;50:5-8.
4. on behalf of the SPRINTT Consortium, Marzetti E, Calvani R, Tosato M, et al. Sarcopenia: an overview. *Aging Clin Exp Res*. 2017;29(1):11-17.
5. Rosenberg IH. Sarcopenia: origins and clinical relevance. *J Nutr*. 1997;127(5):990S-991S.
6. Cruz-Jentoft AJ, Baeyens JP, Bauer JM, et al. Sarcopenia: European consensus on definition and diagnosis: report of the European Working Group on Sarcopenia in Older People. *Age Ageing*. 2010;39(4):412-423.
7. Cruz-Jentoft AJ, Bahat G, Bauer J, et al. Sarcopenia: revised European consensus on definition and diagnosis. *Age Ageing*. 2019;48(1):16-31.
8. Heymsfield SB, Gonzalez MC, Lu J, Jia G, Zheng J. Skeletal muscle mass and quality: evolution of modern measurement concepts in the context of sarcopenia. *Proc Nutr Soc*. 2015;74(04):355-366.
9. Deutz NEP, Ashurst I, Ballesteros MD, et al. The underappreciated role of low muscle mass in the management of malnutrition. *J Am Med Dir Assoc*. 2019;20(1):22-27.
10. Kim JH, Choi SH, Lim S, et al. Assessment of appendicular skeletal muscle mass by bioimpedance in older community-dwelling Korean adults. *Arch Gerontol Geriatr*. 2014;58(3):303-307.
11. Rangel Peniche DB, Raya Giorguli G, 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(1):39-43.
12. 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(6):537-543.
13. van Baar H, Hulshof PJM, Tieland M, de Groot CPGM. Bio-impedance analysis for appendicular skeletal muscle mass assessment in (pre-) frail elderly people. *Clin Nutr ESPEN*. 2015;10(4):e147-e153.
14. Yu S, Powell A, Khow K, Visvanathan R. The performance of five bioelectrical impedance analysis prediction equations against dual X-ray absorptiometry in estimating appendicular skeletal muscle mass in an adult Australian population. *Nutrients*. 2016;8(4):189.
15. Price KL, Earthman CP. Update on body composition tools in clinical settings: computed tomography, ultrasound, and bioimpedance applications for assessment and monitoring. *Eur J Clin Nutr* 2019;73(2):187-193.
16. Cederholm T, Jensen GL, Correia MITD, et al. GLIM criteria for the diagnosis of malnutrition—a consensus report from the global clinical nutrition community. *Clin Nutr*. 2019;38(1):1-9.
17. Kawakami R, Murakami H, Sanada K, et al. Calf circumference as a surrogate marker of muscle mass for diagnosing sarcopenia in Japanese men and women: calf circumference and sarcopenia. *Geriatr Gerontol Int*. 2015;15(8):969-976.
18. Rolland Y, Lauwers-Cances V, Cournot M, et al. Sarcopenia, calf circumference, and physical function of elderly women: a cross-sectional study. *J Am Geriatr Soc*. 2003;51(8):11201124.
19. Kim S, Kim M, Lee Y, Kim B, Yoon TY, Won CW. Calf circumference as a simple screening marker for diagnosing sarcopenia in older Korean adults: the Korean Frailty and Aging Cohort Study (KFACS). *J Korean Med Sci*. 2018;33(20):e151.
20. Akın S, Mucuk S, Öztürk A, et al. Muscle function-dependent sarcopenia and cut-off values of possible predictors in community-dwelling Turkish elderly: calf circumference, midarm muscle circumference and walking speed. *Eur J Clin Nutr*. 2015;69(10):1087-1090.
21. Wen X, Wang M, Jiang C-M, Zhang Y-M. Anthropometric equation for estimation of appendicular skeletal muscle mass in Chinese adults. *Asia Pac J Clin Nutr*. 2011;20(4):551556.
22. Centers for Disease Control and Prevention (CDC), National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey: Body Composition Protocol. Department of Health and Human Services, Centers for Disease Control and Prevention; 2006.
23. Centers for Disease Control and Prevention (CDC), National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey: Body Composition procedures manual. Department of Health and Human Services, Centers for Disease Control and Prevention; 2004.
24. Centers for Disease Control and Prevention (CDC), National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey: Body Composition procedures manual. Department of Health and Human Services, Centers for Disease Control and Prevention; 2002.
25. Centers for Disease Control and Prevention (CDC), National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey: Body composition procedures manual. Department of Health and Human Services, Centers for Disease Control and Prevention; 2000.
26. Gonzalez MC, Barbosa-Silva TG, Heymsfield SB. Bioelectrical impedance analysis in the assessment of sarcopenia. *Curr Opin Clin Nutr Metab Care*. 2018;21(5):366-374.
27. Centers for Disease Control and Prevention (CDC), National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey: Anthropometry and physical activity monitor procedures manual. Department of Health and Human Services, Centers for Disease Control and Prevention; 2005.
28. Centers for Disease Control and Prevention (CDC), National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey: Anthropometry procedures manual. Department of Health and Human Services, Centers for Disease Control and Prevention; 2000.
29. Centers for Disease Control and Prevention (CDC), National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey: Anthropometry procedures manual. Department of Health and Human Services, Centers for Disease Control and Prevention; 2002.
30. Centers for Disease Control and Prevention (CDC), National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey: Anthropometry procedures manual. Department of Health and Human Services, Centers for Disease Control and Prevention; 2004.

31. Mukaka MM. Statistics corner: A guide to appropriate use of correlation coefficient in medical research. *Malawi Med J J Med Assoc Malawi*. 2012;24(3):69-71.
32. Cook D. Detection of influential observation in linear regression. *Technometrics*. 1977;19(1):15-18.
33. Jamaiyah H, Geeta A, Safiza MN, et al. Reliability and technical error of calf circumference and mid-half arm span measurements for nutritional status assessment of elderly persons in Malaysia. *Malays J Nutr*. 2008;14(2):137150.
34. Hsu W-C, Tsai AC, Wang J-Y. Calf circumference is more effective than body mass index in predicting emerging care-need of older adults—results of a national cohort study. *Clin Nutr*. 2016;35(3):735-740.
35. Easton JF, Stephens CR, Román-Sicilia H, Cesari M, Pérez-Zepeda MU. Anthropometric measurements and mortality in frail older adults. *Exp Gerontol*. 2018;110:61-66.
36. Real GG, Frühauf IR, Sedrez JHK, Dall'Aqua EJF, Gonzalez MC. Calf circumference: a marker of muscle mass as a predictor of hospital readmission. *J Parenter Enter Nutr*. 2018;42(8):1272-1279.
37. Bonnefoy M, Jauffret M, Kostka T, Jusot JF. Usefulness of calf circumference measurement in assessing the nutritional state of hospitalized elderly people. *Gerontology*. 2002;48(3):162-169.
38. Barbosa-Silva TG, Bielemann RM, Gonzalez MC, Menezes AMB. Prevalence of sarcopenia among community-dwelling elderly of a medium-sized South American city: results of the *COMO VAI?* study: sarcopenia prevalence in a South American city. *J Cachexia Sarcopenia Muscle*. 2016;7(2):136-143.
39. Hwang A-C, Liu L-K, Lee W-J, Peng L-N, Chen L-K. Calf circumference as a screening instrument for appendicular muscle mass measurement. *J Am Med Dir Assoc*. 2018;19(2):182-184.
40. Sergi G, De Rui M, Veronese N, et al. Assessing appendicular skeletal muscle mass with bioelectrical impedance analysis in free-living Caucasian older adults. *Clin Nutr*. 2015;34(4):667-673.
41. Yoshida D, Shimada H, Park H, et al. Development of an equation for estimating appendicular skeletal muscle mass in Japanese older adults using bioelectrical impedance analysis: estimation of appendicular muscle mass. *Geriatr Gerontol Int*. 2014;14(4):851-857.