Clinical Nutrition 34 (2015) 667–673

Contents lists available at ScienceDirect

Clinical Nutrition

journal homepage: http://www.elsevier.com/locate/clnu

Original article

Assessing appendicular skeletal muscle mass with bioelectrical impedance analysis in free-living Caucasian older adults

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ARTICLE INFO

Article history:
Received 31 May 2014
Accepted 20 July 2014

Keywords:
Sarcopenia
Body composition
Prediction equation
Limbs lean mass
Older adults

SUMMARY

Background & aims: Aging is characterized by a loss of appendicular skeletal muscle mass (ASMM) leading to physical disability and death. Bioelectrical impedance analysis (BIA) is reliable in estimating ASMM but no prediction equations are available for elderly Caucasian subjects. The aim of the study was to develop and validate an equation derived from bioelectrical impedance analysis (BIA) to predict appendicular skeletal muscle mass (ASMM) in healthy Caucasian elderly subjects, taking dual X-ray absorptiometry (DXA) as the reference method, and comparing the reliability of the new equation with another BIA-based model developed by Kyle et al. (Kyle UG, Genton L, Hans D, Pichard C, 2003).

Methods: With a cross-sectional design, 296 free-living, healthy Caucasian subjects (117 men, 179 women) over 60 years of age were enrolled. Lean mass of limbs was measured with DXA to ascertain ASMM ($ASMM_{DxA}$). Whole-body tetrapolar BIA was performed to measure resistance (Rz), resistance normalized for stature (RI), and reactance (Xc). The BIA multiple regression equation for predicting ASMM was developed using a double cross-validation technique. The predicted ASMM values were compared with $ASMM_{Kyle}$, i.e. ASMM estimates derived from the model developed by Kyle et al. (Kyle et al., 2003).

Results: Cross-validation resulted in a unique equation using the whole sample: ASMM (kg) = −3.964 + (0.227*RI) + (0.095*weight) + (1.384*sex) + (0.064*Xc) [$R^2 = 0.92$ and SEE = 1.14 kg]. In our sample, $ASMM_{Kyle}$ differed significantly from the $ASMM_{DxA}$ ($p < 0.0001$), with a mean error of −0.97 ± 1.34 kg (5.1 ± 6.9%). Unlike the present BIA prediction equation, the Kyle et al. model showed a correlation between the bias and the mean of $ASMM_{DxA}$ and $ASMM_{Kyle}$ ($r = -0.406$, $p < 0.001$).

Conclusion: The new BIA equation provides a valid estimate of ASMM in older Caucasian adults.

1. Introduction

Aging is associated with sarcopenia, a syndrome characterized by a progressive loss of skeletal muscle mass (SMM), muscle strength and functionality, leading to a higher risk of physical disability, poor quality of life and death [1]. This process can be schematically divided into three increasingly serious stages: pre-sarcopenia, sarcopenia and severe sarcopenia. The element common to these three stages is a decrease in skeletal muscle mass, which is the only marker of sarcopenia detectable in the pre-clinical phase [2].

In assessing muscle mass, the appendicular portion of the SMM (ASMM) is particularly important. It accounts for 73–75% of the total SMM [3], and a decrease in ASMM is associated with disability [4] because it is involved primarily in physical activities [5].

Assessing muscle mass (and ASMM in particular) is challenging, the choice of method depending on the circumstances. Radiological methods such as computerized tomography and magnetic resonance imaging are precise but costly and only available at

Abbreviations: ASMM, appendicular skeletal muscle mass; BIA, bioelectrical impedance analysis; DXA, dual X-ray absorptiometry; RI, resistive index; Rz, resistance; SMM, skeletal muscle mass; Xc, reactance.

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http://dx.doi.org/10.1016/j.clnu.2014.07.010
0261-5614/

specialized facilities. Measuring muscle metabolites, including creatinine and 3-methylhistidine, demands dietary control and analytical laboratory equipment. Anthropometry is a simple field method that is not very accurate because it is based on dubious assumptions. Another option is dual X-ray absorptiometry (DXA), which is an acceptable reference technique for assessing whole body and appendicular body composition [6,7]. But DXA cannot be used routinely because the method is costly, it is not portable, and it entails exposure to radiation. A safe, non-invasive, portable and reliable alternative is bioelectrical impedance analysis, a method that can be used both in clinical settings and in the field for epidemiological studies.

Although numerous papers have reported on the use of BIA to predict fat-free mass [8] or SMM [9], to our knowledge, the only BIA-derived equations specifically for predicting ASMM in elderly people and taking DXA for reference are the one developed by Kim et al. [10] and that of Yoshida et al. [11]. Nevertheless, been developed in Asian subjects, these equations cannot be used in Caucasian people due to the well-known anthropometric differences. No ASMM prediction equations are available for elderly Caucasian subjects, and the only option is to use the Kyle et al. equation [12], which was obtained in a sample of adults of all ages (20–94 years). The assumptions behind BIA are that the body (limbs and trunk) can be considered as a single conductive cylinder, and the relationship between the main cross-sectional areas remains the same. This model should change with aging, however, because older people experience a gradual reduction in the cross-sectional area of their limbs and a concomitant increase in that of their trunk [13,14]. BIA equations specifically generated from a sample of elderly subjects would consequently predict ASMM better than equations derived from a sample population of all ages. The aim of this study was thus to develop and validate a BIA equation for predicting ASMM in healthy elderly Caucasian subjects, taking DXA for reference. We also compared the reliability of our new equation and the one developed by Kyle in a sample of elderly people.

2. Materials and methods

2.1. Subjects

This cross-sectional study was conducted at the Padova University – Geriatrics Department on a sample of Caucasian subjects over 60 years of age recruited on a voluntary basis among the elderly people attending a twice-weekly mild fitness program at public gyms in Padova. Their healthy condition was established by trained medical personnel, based on their clinical history, a clinical examination and biohumoral tests. Individuals with skeletal deformities that might affect their height (i.e. kyphosis, scoliosis), or significant cardiovascular or lung diseases, uncontrolled metabolic disease (diabetes, anemia or thyroid disease), electrolyte abnormalities, cancer or inflammatory conditions in the last 5 years were ruled out. Any use of drugs (corticosteroids, hormones, etc.) that might interfere with body composition was also a reason for exclusion.

Among 304 screened subjects, 8 were excluded because of presence of non-inclusion criteria (3 participants with kyphosis, 2 with cancer in the previous 5 years, 2 with uncontrolled insulin-dependent diabetes, and 1 taking steroids). Therefore, the final sample consisted of 296 subjects.

This study was designed in accordance with the Helsinki Declaration and approved by the local Ethical Committee (IRB approval #491/2011). All participants were fully informed about the nature, purpose, procedures and risks of the study, and gave their written informed consent.

2.2. Methods

Each subject underwent all the following measures on the same day.

- Anthropometric measurements: body weight was measured to the nearest 0.1 kg using a standard scale (Seca, Hamburg, Germany) with subjects wearing light clothing and no shoes; barefoot standing height was measured to the nearest 0.1 cm with a wall-mounted stadiometer (Magnimeter, Raven Equipment Ltd, Dunmow, Essex, UK). BMI was calculated as the weight in kilograms divided by the height in meters squared.
- Multi-dimensional assessment:
  - functional status was assessed using Activity of Daily Living (ADL) [15] and Instrumental ADL (IADL) [16] scales;
  - physical performance was assessed with the Short Physical Performance Battery (SPPB) [17] including gait speed, five timed chair stands, and the tandem test. Performance was scored from 0 to 12, higher scores indicating a better lower body function;
  - health status was assessed with the Cumulative Illness Rating Scale (CIRS) [18], which classifies comorbidities among 13 organ systems and grades each condition from 1 (no problem) to 5 (severely incapacitating or life-threatening conditions). The comorbidity index (CIRS-CI) is given by the number of conditions graded as $\geq$3.
- Dual x-ray absorptiometry: fat-free mass (FFM), lean mass (LM, i.e. FFM less bone mineral mass) and fat mass (FM) were assessed by means of a whole body scan using a fan-beam densitometer (Hologic QDR Discovery A, Hologic Italy). Appendicular skeletal muscle mass ($ASMM_{DxA}$) was calculated as the sum of the lean mass of the limbs, as described by Heymsfield et al. [19]. ASMM was normalized in relation to the subject's height (ASMM/height in meters squared) to obtain the ASMM index ($ASMMI_{DxA}$, kg/m^2). The scanner was calibrated daily using a standard calibration block supplied by the manufacturer. All metal items were removed before densitometry. Subjects wearing only underwear were placed supine with their arms at their sides, slightly away from their trunk and correctly centered on the scanning field. The scan took about 180 s and the radiation dose per individual was 0.01 mGy (1.0 mrad). To our knowledge, there is no information available on the precision of the QDR Discovery A for measuring body composition, but for the QDR 4500A (the previous Hologic model) the coefficients of variation are 1.1% for total mass, 1.97% for FM and 1.46% for LM [20].
- BIA: whole-body tetrapolar BIA (BIA 101 Anniversary AKERN/RJL Systems; Florence, Italy) was performed using an alternating sinusoidal electric current of 400 μA at a single operating frequency of 50 kHz. The device was calibrated every morning using the standard control circuit supplied by the manufacturer with a known impedance (resistance = 380 Ω; reactance = 47 Ω). The device's precision was 1% for resistance (Rz), and 5% for reactance (Xc). BIA was performed with subjects supine with their limbs slightly away from their body, after an overnight fast, and bladder voiding. To avoid inter-observer errors, all BIA measurements were taken by the same trained investigator. Active electrodes (BIATRODES® Akern Srl; Florence, Italy) were placed on the right side on conventional metacarpal and metatarsal lines, recording electrodes in standard positions at the right wrist and ankle [21]. All resistance measurements were normalized for stature (height in centimeters squared/Rz) to obtain the resistive index (RI). The repeatability and accuracy of the resistance and reactance measurements enabled the smallest changes to be recorded to a resolution of 0.1 Ω.