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Total and appendicular lean mass reference ranges for Australian men and women: The Geelong Osteoporosis Study

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Conflicts of interest

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SPECIFIC REMARKS

Mini abstract

The diagnosis of muscle wasting and sarcopenia involves assessing lean mass against young adult reference data. These reference ranges for total and appendicular lean mass measured using dual energy X-ray absorptiometry provide data that may be useful for identifying lean mass deficits in men and women.

Abstract

Purpose

The aim of this study was to develop reference ranges for total and appendicular lean mass measured using dual energy X-ray absorptiometry (DXA) from a randomly selected population-based sample of men and women residing in south-eastern Australia.

Methods

Men (n=1411) and women (n=960) aged 20-93 years, enrolled in the Geelong Osteoporosis Study, were randomly selected from the Barwon Statistical Division using the electoral roll as a sampling frame in 2001-06 (67% participation) and 1993-97 (77% participation), respectively. Using DXA (Lunar DPX-L or Prodigy Pro) at baseline for men and at the 10-year follow-up for women (2004-08), total and appendicular lean mass were measured. Means and standard deviations for each lean mass measure (absolute and relative to height-squared) were generated for each age decade and cut-points equivalent to T-scores of -2.0 and -1.0 were calculated using data from young adult men and women aged 20-39 years.

Results

Young adult reference data were derived from 374 men and 308 women. Cut-points for relative appendicular lean mass equal to T-scores of -2.0 and -1.0 were 6.94 kg/m² and 7.87 kg/m² for men and 5.30 kg/m² and 6.07 kg/m² for women. The proportion of men and women aged ≥80 years with a T-score less than -2.0 was 16.0% and 6.2%, respectively.

Conclusion

These reference ranges may be useful for identifying lean mass deficits in the assessment of muscle wasting and sarcopenia.

Keywords

Dual energy X-ray absorptiometry, lean mass, muscle-wasting, reference values, sarcopenia

INTRODUCTION

The availability of population-specific reference data for lean mass may improve the assessment of the age- and illness-related muscle wasting that contributes to sarcopenia and cachexia, respectively. In 2010, the European Working Group on Sarcopenia in Older People (EWGSOP) proposed diagnostic criteria, which included the assessment of lean mass and muscle function against young adult reference standards [1]; however, few reference data for these domains of sarcopenia, including lean mass, exist. Proposed criteria for the assessment of cachexia also address the importance of assessing muscle strength and lean mass as well as other factors including weight loss, fatigue and relevant biomarkers [2].

Lean mass can be estimated using computed tomography (CT), magnetic resonance imaging (MRI), bioelectrical impedance analysis (BIA) and dual energy X-ray absorptiometry (DXA). CT and MRI estimates of the cross-sectional area of skeletal muscle, free of interstitial adipose tissue, correlate very highly with direct measurements from cadavers ($r = 0.97$ for both imaging techniques) [3]. Lean mass measured by DXA is a composite of non-fat and non-bone tissue and is highly correlated with skeletal muscle mass measured using MRI technology ($r = 0.94$ for the total body and 0.91 and for the leg) [4]. Although CT and MRI are considered criterion methods for measuring skeletal muscle mass, DXA may be more appropriate for research and clinical practice because of its comparatively lower cost, accessibility and lower radiation dose [1,5].

Reference data for lean mass measured using DXA exist for White populations with mixed European origin in the US [6] and for specific European populations [7-9] but the extent of their generalisability is not known. Country- or population-specific reference data developed in defined populations may help to improve the validity of muscle wasting assessment. The aim of this study was to develop reference data for total and appendicular lean mass (absolute

and relative to height-squared) measured using DXA in population-based randomly selected men and women residing in south-eastern Australia.

METHODS

Study participants

This study utilised cross-sectional data collected by the Geelong Osteoporosis Study (GOS) at the baseline assessment for men (2001-06) and the 10-year assessment for women (2004-08; baseline assessments occurred in 1993-97). At baseline for the male and female cohorts, at least 100 individuals in each 5-year age group between 20 and 69 years and 200 individuals in the age groups 70-79 and ≥ 80 years were randomly selected from the Barwon Statistical Division in south-eastern Australia using the electoral roll as a sampling frame. Of 2296 men who were eligible for inclusion in the study, 1540 agreed to participate (67% participation); 1494 of 1938 eligible women participated in the study at baseline (77% participation). An additional 221 women aged 20-29 years on the 2005 electoral roll were randomly selected using the sampling procedure described above at the 10-year follow-up for women. A detailed background to the GOS has been published [10]. At least 99% of men and women participating at the baseline assessments of the GOS were Caucasian [11,12]. Further information about attrition rates at follow-up for the GOS is available elsewhere [10]. The study was approved by the Barwon Health Human Research Ethics Committee and all participants gave their informed consent.

Individuals bilaterally affected by objects or devices such as prostheses, plates, screws, silicone implants, pacemakers or plaster casts were not included in analyses. Small pieces of jewellery attached to the hands or head, finger amputations, dental work and hearing aids (or other reasons that may have affected the scan of the head) were ignored. Individuals were

also excluded from analyses if: (i) their weight was ≥ 120 kg (the weight limit of the DXA scanners), (ii) both sides of their body (not including their feet) were incompletely scanned (e.g. they were too large), (iii) one side of their body was incompletely scanned and the opposite side was affected by objects or devices, or (iv) they did not provide a total body scan (e.g. they could not assume the correct position). Participants were not excluded based on any other criteria relating to their health status.

Of the 1540 men recruited at baseline, 1467 were scanned using DXA to estimate their body composition. Analyses excluded 56 men: 6 were missing body composition data for the total body, 21 weighed ≥ 120 kg, 19 were bilaterally affected by objects or devices, 2 were unilaterally affected by an object or device and the opposite side of their body was incompletely scanned and 8 did not have a complete scan for both sides of their body. In analyses for women, 1071 of 1715 (including 1494 women who participated at baseline and the 221 young women subsequently recruited), underwent a DXA scan at the 10-year follow-up assessment. Our analyses excluded 111 women: 21 did not provide body composition data for the total body, 12 weighed ≥ 120 kg, 30 were bilaterally affected by objects or devices, 2 were unilaterally affected by an object or device and the opposite side of their body was incompletely scanned and 46 did not have a complete scan for both sides of their body.

Body composition and anthropometry

Consistent with the approach used by Baumgartner et al, lean mass measurements for both arms and legs were summed to give an estimate of appendicular lean mass [13]; total body lean mass was a composite of lean mass values for the arms, legs, trunk (including the neck) and head. Men and women were initially scanned with a DPX-L scanner (software version 1.31; Lunar, Madison, WI, USA) until it was replaced with a Lunar Prodigy Pro (GE Medical

Systems Lunar, Madison, WI, USA. Of the 1411 men included in analyses, 517 were scanned with the DPX-L and 894 with the Prodigy. Of the 960 women included in analyses, 57 were scanned with the Prodigy. We have previously shown that there is no difference in bone mineral density measured at the lumbar spine or femoral neck in individuals scanned with both the DPX-L and Prodigy DXA scanners [12]. The coefficient of variation for total lean mass was 1.97% for the DPX-L and 0.85% for the Prodigy.

For individuals who were unilaterally affected by objects or devices or who had an incomplete scan for one side of their body, total and appendicular lean mass measures were derived by doubling values for the unaffected side of their body. This affected 111 men (56 with unilateral objects or devices) and 104 women (32 with unilateral objects or devices).

Both height (± 0.1 cm) and weight (± 0.1 kg) were measured but weight derived from participants' total body DXA scan (a composite of their total fat mass, lean mass and bone mineral content) was used in analyses.

Statistical analyses

Men and women were analysed separately. Relative total and appendicular lean mass were calculated for each individual by dividing lean mass values in kilograms by the square of height in metres. Relative appendicular lean mass is equivalent to the skeletal muscle mass index used by Baumgartner et al [13]. Gender-specific means and standard deviations for absolute and relative total and appendicular lean mass were calculated for all adults and for a young adult reference sample aged 20-39 years. Cut-points were calculated using young adult reference data and were equal to a T-score of -2.0 and -1.0 (the number of standard deviations below the young adult reference mean). The proportions of men and women

within each 10-year age group with T-scores < -2.0, equal to or between -2.0 and -1.0 or >-1.0 were calculated.

Associations between absolute total and appendicular lean mass and each of the covariates, age, height and weight were examined using linear regression. Age, weight and height were centred around the mean for the group before examination in models. The likelihood ratio test was used to determine whether the association between each absolute lean mass measure and each of age, weight and height was linear or non-linear by comparing the fit of models with and without squared terms; a *P*-value <0.05 was considered evidence of a non-linear relationship. All regressions for absolute total and appendicular lean mass including covariates and their squares were explored. The selection of parsimonious models for absolute total and appendicular lean mass for men and women was based on maximising the coefficient of determination (R^2) while minimising each of the Mallows' Cp statistic, standard error and the number of covariates in the multivariable models. Whether linear regression models satisfied the assumptions of linear regression was determined by examining the residuals for normal distribution using quantile-quantile plots and the variance of residuals when plotted against the predicted values. Relationships between covariates and absolute total and appendicular lean mass were displayed as scatterplots with 95% prediction intervals. All statistical analyses were performed using Stata version 11.2 (StataCorp LP, College Station, TX, USA).

Sensitivity analyses

Reference ranges were re-calculated after excluding individuals whose total and appendicular lean mass were derived by doubling measurements for one side of their body and those who were 190 cm or taller to account for those whose feet may not have been captured in the total body scan. Linear regression models for total and appendicular lean mass were also re-

examined using these smaller samples. For these two sensitivity analyses a total of 135 men and 104 women were excluded. Of the excluded men, 29 were 190 cm or taller, 111 had lean mass measures derived by doubling the unaffected side of their body, and 5 had both. Of the excluded women, all had derived lean mass measures only. In separate sensitivity analyses linear regression models were re-examined using individuals' measured weight as opposed to that derived from their total body DXA scan.

RESULTS

Characteristics of the study participants are shown in Table 1. Young adult reference data were generated in 374 men and 308 women aged 20-39 years. These data, together with cut-points equivalent to T-scores of -2.0 and -1.0 for absolute and relative total and appendicular lean mass derived from young adult men and women are displayed in Table 2. Gender-specific means and standard deviations for absolute and relative lean mass measures by 10-year age group are displayed in Tables 3 and 4, respectively. Both absolute lean mass measures appeared to decrease from 30-39 years in men and from 20-29 years in women (Table 3). In men, both relative lean mass measures increased with age up to 40-49 years and then steadily decreased. In women, relative total lean mass increased with age while relative appendicular lean mass remained relatively stable until both decreased after approximately 50-59 years (Table 4). The proportions of men and women by 10-year age group with relative appendicular lean mass within defined T-score categories (i.e. T-scores <-2.0, equal to or between -2.0 and -1.0 or >-1.0) are listed in Table 5.

The likelihood ratio test was used to determine whether univariable relationships between absolute lean mass measures and covariates were linear or non-linear. For men and women the relationship with each lean mass measure was non-linear for age (Fig. 1) and linear for height (Fig. 2). The relationship between weight and appendicular lean mass was non-linear

in men and linear in women; for total lean mass the relationship with weight was linear for both genders (Fig. 3). In men, age explained 16.3% of the variance in total lean mass and 26.4% of the variance in appendicular lean mass. Corresponding values were lower in women, with age explaining 11.9% of the variance in total lean mass and 15.5% of the variance in appendicular lean mass (Table 6). In men and women, weight and height each explained more of the variance in lean mass measures than age alone (Table 6).

Parsimonious multivariable models for absolute total and appendicular lean mass for men and women included age, weight and height; overall these variables explained 76.5% and 75.6% of the variance in total and appendicular lean mass in men and 67.0% and 70.9% in women (Table 6). The distributions of residuals for models displayed in Table 6 were approximately normal and their variances were relatively constant across predicted values (data not shown).

Sensitivity analyses

Mean total and appendicular lean mass ($\pm$ standard deviation) for men ($n=1276$) was 57.5 ± 6.8 kg and 26.0 ± 3.7 kg; corresponding values for women ($n=856$) were 39.1 ± 4.2 kg and 17.6 ± 2.3 kg, respectively. Mean relative total lean mass for men was 18.9 ± 1.7 kg/m² and 8.5 ± 0.9 kg/m² for relative appendicular lean mass; corresponding values for women were 14.8 ± 1.2 kg/m² and 6.7 ± 0.7 kg/m², respectively. Young adult reference data were generated in 347 men and 276 women aged 20-39 years. Mean absolute total lean mass in young adult men was 59.4 ± 6.8 kg and 27.8 ± 3.6 kg for absolute appendicular lean mass; corresponding values for the relative measures were 18.8 ± 1.7 kg/m² and 8.8 ± 0.9 kg/m², respectively. Mean absolute total lean mass in young adult women was 40.2 ± 4.2 kg and 18.3 ± 2.3 kg for absolute appendicular lean mass; values were 14.7 ± 1.2 kg/m² and 6.7 ± 0.6 kg/m² for the relative measures, respectively. The values were similar (although slightly lower in some cases) to those generated in all young adult men and women regardless of how

their body composition values were derived; the same was true for the distribution of absolute and relative total and appendicular lean mass values by 10-year age group (results not shown). For men, the exclusion of individuals who were 190 cm or taller and whose body composition was doubled did not markedly change prevalence estimates, but the estimates for women appeared greater.

A sensitivity analysis that re-examined linear regression models for absolute total and appendicular lean mass in only those men and women who were less than 190 cm tall and who did not have their body composition doubled had no apparent effect on the non-linear relationship between each absolute lean mass measure and age or on the selection of parsimonious models (results not shown). The univariable relationship between both lean mass measures and each of weight and height in men and women was unchanged in sensitivity analyses. A separate sensitivity analysis that re-examined models for absolute lean mass measures using participants' measured weight as opposed to that derived from their DXA scan also had no effect on univariable models or on the selection of parsimonious models (results not shown) but the relationship between measured weight and absolute total lean mass was non-linear rather than linear in men.

DISCUSSION

This study provides gender-specific reference data for absolute and relative total and appendicular lean mass measured using DXA. Alone or in combination with measures of muscle strength and physical performance, these data may be useful for assessing sarcopenia in the adult population. These data may also have utility in the assessment of muscle wasting in cachexia.

Cut-points for relative appendicular lean mass equivalent to a T-score of -2.0 derived from our young reference samples aged 20-39 years were 6.94 for men and 5.30 kg/m² for women. These values are lower than those derived from a US non-Hispanic White sample of 107 men and 122 women aged 18-40 years for the same lean mass index measured using a Lunar DXA (7.26 and 5.45 kg/m², respectively) [13]. The authors of this study stated that the representativeness of the young adult sample that they used was 'not known'. A cut-point of 5.4 kg/m² for relative appendicular lean mass measured using DXA (Hologic or Lunar) derived from a sample of 216 healthy Danish women aged 18-39 years [9] is similar to our cut-point for randomly selected women. The same study also reported a cut-point for absolute appendicular lean mass of 14.0 kg for women compared to ours of 13.64 kg. Small differences between cut-points may be real or a result of the limitations associated with estimating lean mass using DXA, which does not differentiate between skeletal muscle, interstitial fat, skin and connective tissue. Another study that published cut-points derived from young adults aged 18-39 years measured skeletal muscle using BIA and expressed it as a percentage of body mass rather than indexing it to height-squared [14]. Our cut-points for absolute and relative total lean mass were 45.58 kg and 15.33 kg/m² for men and 31.42 kg and 12.07 kg/m² for women. Raw data from which comparable cut-points may be calculated have been published [7,15,6].

Others have used reference data derived from men aged 24-45 years for fat-free mass (indexed to body surface area) measured using BIA [16], or from premenopausal women and men aged <50 years for various lean mass measures quantified using DXA (Hologic) [17]. Ideally, such reference data should be based on the age range of peak lean mass. A US study measured fat-free mass (indexed to height-squared) in men and women aged 18-110 years using DXA (Lunar) and generated quadratic prediction equations that described how lean

mass varied across the adult lifespan; the turning point (maximum) was 23.5 years for men and 48.1 years for women [18]. A study in Italian women showed that absolute total lean mass measured using DXA (Hologic) significantly decreased after 40-49 years [7]. A Swedish study reported that absolute total lean mass measured using DXA (Lunar) decreased from 20-29 years (the youngest age group explored) in men and women, except for apparently increasing after 70-79 years in the latter [15]. A study in US non-Hispanic Whites, which measured lean mass using DXA (Hologic), showed that the apparent peak in relative total lean mass was 45-54 years for men and 45-49 years for women while for relative appendicular lean mass it was 40-44 years in both genders [6]. While the peak age for lean mass measures (absolute or relative to height-squared) may not be consistent for different geographical regions, this is difficult to fully appreciate as not all studies reviewed derived this value mathematically and some, including this study, report average lean mass values by age group without providing statistical inferences about differences between groups. Despite this, there is some evidence of differences in the distribution of lean mass measures and in the age range of peak lean mass in men and women.

We have shown that the prevalence of relative appendicular lean mass less than a T-score of -2.0 in men and women aged ≥ 80 years is 16.0 % and 6.2 %, respectively. As a small number of elderly women had low appendicular lean mass, any reduction in the sample population may have a large impact on prevalence estimates. A US study that estimated lean mass in their participants using predictive equations and that used cut-points generated in young adults aged 18-40 years reported that the proportion of population-based non-Hispanic White men and women aged >80 years with a relative appendicular lean mass T-score below -2.0 was 52.6% and 43.2%, respectively [13]. Another study in the US, using the same cut-points, reported similar estimates in their Caucasian sample of male and female volunteers aged >80

years (52.9% and 31.0%, respectively) [19]. A study in healthy Danish women aged >70 years reported that 12.3% had a relative appendicular lean mass less than a T-score of -2.0 [9]. While these prevalence estimates are at least double those reported in the current study for population-based men and women aged ≥ 80 , the differences may be explained by cohort-effects (the former study was published in 1998 and the latter two studies in 2002) or differences in study population characteristics.

The EWGSOP recognise 'pre-sarcopenia' as a state characterised by low muscle mass without the associated attenuation in muscle strength or physical performance that is characteristic of sarcopenia [1]. Notwithstanding the limitations associated with diagnosing sarcopenia without assessing muscle function, these reference data may help to identify early stage sarcopenia.

We have shown that the relationship between age and absolute total and appendicular lean mass is negative and non-linear in men and women. This non-linear relationship is consistent with a study in a multi-ethnic population of men and women aged 18-110 years in the US, which measured fat-free mass indexed to height-squared using DXA and generated equations specific for each ethnic group explored [18]. In another US study, the age-related decline in absolute total lean mass in men (23-90 years) and women (21-93 years) was linear [17]; this was also the case for both absolute total and appendicular lean mass in Danish women of a similar age (18-85 years) [9].

Our data showed age to be associated with lean mass measures independent of height and weight, supporting longitudinal findings in other studies. In a longitudinal study with an average follow-up period of five years, appendicular lean mass decreased in both men and women who did not experience significant changes in height or weight over this time; the decrease in lean mass was accompanied by an increase in fat mass [20]. The influence of

changes in height and weight on changes in lean mass is marked. We found that height and weight appeared to explain more of the variance in both absolute lean mass measures than age alone, which is consistent with another study that reported BMI explained approximately 50% of the variance in relative appendicular lean mass in men [19].

More than 99% of male and female GOS participants self-identified as Caucasian at baseline [11,12]. Ethnicity-specific prediction equations for fat-free mass indexed to height-squared differ significantly [18] and so the validity of reference data may be improved by using homogenous samples. Given the heterogeneity of the Australian Caucasian population, these reference data may be more valid in populations with mixed-European origins. Reference data may need to be developed for different DXA models across different countries and ethnicities.

The EWGSOP recommend the use of 'healthy young adult' reference data to develop cut points for the different domains of sarcopenia [1] but these guidelines are not consistent with those developed by the World Health Organisation for BMD reference data used in the assessment of osteoporosis, which identify the importance of deriving these data from a randomly selected representative population [21]. The representativeness of our male and female samples is high as individuals used to generate these data were not selected based on their health status. Whether or not our sampling strategy and inclusion criteria lead to biased estimates of sarcopenia or muscle wasting in the population needs to be investigated further.

Despite confirming the validity of cut-points generated from samples that include individuals with a partially invalid total body scan using a sensitivity analysis, the representativeness of these data may be affected by our exclusion criteria. As a consequence, these data may not be representative of individuals who weigh ≥ 120 kg or of those with bilateral prostheses, including those with objects or devices in the spine, knees, hips and breasts.

The reference data presented here were developed in population-based samples of men and women randomly selected from a region in south-eastern Australia. These data provide information needed to assess lean mass deficits in sarcopenia or cachexia and can be used for these purposes in Caucasian Australians and possibly in similar Caucasian populations of mixed European origin. More work may be needed to develop similar data for other populations and for other DXA devices.

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REFERENCES

1. Cruz-Jentoft AJ, Baeyens JP, Bauer JM, Boirie Y, Cederholm T, Landi F, Martin FC, Michel J-P, Rolland Y, Schneider SM, Topinkova E, Vandewoude M, Zamboni M (2010) Sarcopenia: European consensus on definition and diagnosis: Report of the European Working Group on Sarcopenia in Older People. *Age Ageing* 39 (4):412-423
2. Evans WJ, Morley JE, Argilés J, Bales C, Baracos V, Guttridge D, Jatoi A, Kalantar-Zadeh K, Lochs H, Mantovani G, Marks D, Mitch WE, Muscaritoli M, Najand A, Ponikowski P, Rossi Fanelli F, Schambelan M, Schols A, Schuster M, Thomas D, Wolfe R, Anker SD (2008) Cachexia: A new definition. *Clin Nutr* 27 (6):793-799

3. Mitsiopoulos N, Baumgartner RN, Heymsfield SB, Lyons W, Gallagher D, Ross R (1998) Cadaver validation of skeletal muscle measurement by magnetic resonance imaging and computerized tomography. *J Appl Physiol* 85 (1):115-122
4. Chen Z, Wang Z, Lohman T, Heymsfield SB, Outwater E, Nicholas JS, Bassford T, LaCroix A, Sherrill D, Punyanitya M, Wu G, Going S (2007) Dual-energy X-ray absorptiometry is a valid tool for assessing skeletal muscle mass in older women. *J Nutr* 137 (12):2775-2780
5. Andreoli A, Scalzo G, Masala S, Tarantino U, Guglielmi G (2009) Body composition assessment by dual-energy X-ray absorptiometry (DXA). *Radiol Med* 114 (2):286-300
6. Kelly TL, Wilson KE, Heymsfield SB (2009) Dual energy X-ray absorptiometry body composition reference values from NHANES. *PloS One* 4 (9):e7038-e7038
7. Andreoli A, Bazzocchi A, Celi M, Lauro D, Sorge R, Tarantino U, Guglielmi G (2011) Relationship between body composition, body mass index and bone mineral density in a large population of normal, osteopenic and osteoporotic women. *Radiol Med* 116 (7):1115-1123
8. Karlsson MK, Obrant KJ, Nilsson BE, Johnell O (2000) Changes in bone mineral, lean body mass and fat content as measured by dual energy X-ray absorptiometry: A longitudinal study. *Calcif Tissue Int* 66 (2):97-99
9. Tanko LB, Movsesyan L, Mouritzen U, Christiansen C, Svendsen OL (2002) Appendicular lean tissue mass and the prevalence of sarcopenia among healthy women. *Metabolism* 51 (1):69-74
10. Pasco JA, Nicholson GC, Kotowicz MA (2012) Cohort profile: Geelong Osteoporosis Study. *Int J Epidemiol* 41 (6):1565-1575
11. Henry MJ, Pasco JA, Seeman E, Nicholson GC, Sanders KM, Kotowicz MA (2001) Assessment of fracture risk: value of random population-based samples--the Geelong Osteoporosis Study. *J Clin Densitom* 4 (4):283-289

12. Henry MJ, Pasco JA, Korn S, Gibson JE, Kotowicz MA, Nicholson GC (2010) Bone mineral density reference ranges for Australian men: Geelong Osteoporosis Study. *Osteoporos Int* 21 (6):909-917
13. Baumgartner RN (1998) Epidemiology of sarcopenia among the elderly in New Mexico. *Am J Epidemiol* 147 (8):755-763
14. Janssen I, Heymsfield SB, Ross R (2002) Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability. *J Am Geriatr Soc* 50 (5):889-896
15. Karlsson MK, Gärdsell P, Johnell O, Nilsson BE, Akesson K, Obrant KJ (1993) Bone mineral normative data in Malmö, Sweden. Comparison with reference data and hip fracture incidence in other ethnic groups. *Acta Orthop Scand* 64 (2):168-172
16. Bahat G, Saka B, Tufan F, Akin S, Sivrikaya S, Yucel N, Erten N, Karan MA (2010) Prevalence of sarcopenia and its association with functional and nutritional status among male residents in a nursing home in Turkey. *Aging Male* 13 (3):211-214
17. Melton LJ, 3rd, Khosla S, Crowson CS, O'Connor MK, O'Fallon WM, Riggs BL (2000) Epidemiology of sarcopenia. *J Am Geriatr Soc* 48 (6):625-630
18. Hull HR, Thornton J, Wang J, Pierson RN, Kaleem Z, Pi-Sunyer X, Heymsfield S, Albu J, Fernandez JR, VanItallie TB, Gallagher D (2011) Fat-free mass index: changes and race/ethnic differences in adulthood. *Int J Obes* 35 (1):121-127
19. Iannuzzi-Sucich M, Prestwood KM, Kenny AM (2002) Prevalence of sarcopenia and predictors of skeletal muscle mass in healthy, older men and women. *J Gerontol A Biol Sci Med Sci* 57 (12):M772-M777
20. Gallagher D, Ruts E, Visser M, Heshka S, Baumgartner RN, Wang J, Pierson RN, Pi-Sunyer FX, Heymsfield SB (2000) Weight stability masks sarcopenia in elderly men and women. *Am J Physiol Endocrinol Metabol* 279 (2):E366-E375

21. World Health Organisation (2003) Prevention and management of osteoporosis. Report of a WHO scientific group. World Health Organ Tech Rep Ser 921:1-164, back cover

TABLES

Table 1: Characteristics of study participants displayed as median (interquartile range) or mean $\pm$ standard deviation.

	Men	Women
	n=1411	n=960
Age (years)	55.6 (39.0 – 72.6)	50.6 (34.4 – 65.9)
Weight (kg) [*]	82.02 $\pm$ 12.37	69.41 $\pm$ 12.92
Height (m)	1.75 $\pm$ 0.07	1.62 $\pm$ 0.07

^{*} derived from dual energy X-ray absorptiometry scan

Table 2: Young adult (20-39 years) reference data for absolute (kg) and relative (indexed to height-squared; kg/m²) total and appendicular lean mass and cut-points equivalent to T-scores of -1.0 and -2.0*.

	Men			Women		
	n=374			n=308		
	Mean $\pm$ SD	T-score = -1.0	T-score = -2.0	Mean $\pm$ SD	T-score = -1.0	T-score = -2.0
Total lean mass	60.10 $\pm$ 7.26	52.84	45.58	40.86 $\pm$ 4.72	36.14	31.42
Appendicular lean mass	28.16 $\pm$ 3.79	24.37	20.58	18.72 $\pm$ 2.54	16.18	13.64
Relative total lean mass	18.79 $\pm$ 1.73	17.06	15.33	14.93 $\pm$ 1.43	13.50	12.07
Relative appendicular lean mass	8.80 $\pm$ 0.93	7.87	6.94	6.84 $\pm$ 0.77	6.07	5.30
<i>SD</i> standard deviation						

*T-score=-1.0, lean mass value one SD below the young adult reference mean; T-score=-2.0, lean mass value two SDs below the young adult reference mean

Table 3: Absolute total and appendicular lean mass (kg) for men and women by ten-year age group and for the full age range (20-93 years; displayed as mean $\pm$ standard deviation)

Age group	Men			Women		
	n	Total lean mass	Appendicular lean mass	n	Total lean mass	Appendicular lean mass
20-29	180	59.54 $\pm$ 6.86	28.00 $\pm$ 3.60	176	41.22 $\pm$ 5.04	18.95 $\pm$ 2.66
30-39	194	60.61 $\pm$ 7.59	28.31 $\pm$ 3.96	132	40.38 $\pm$ 4.23	18.41 $\pm$ 2.35
40-49	203	60.43 $\pm$ 6.71	27.86 $\pm$ 3.59	161	40.06 $\pm$ 4.10	18.27 $\pm$ 2.26
50-59	215	59.34 $\pm$ 5.99	26.95 $\pm$ 3.04	159	39.89 $\pm$ 4.10	18.14 $\pm$ 2.26
60-69	206	58.39 $\pm$ 6.43	25.83 $\pm$ 3.16	146	38.77 $\pm$ 3.63	17.18 $\pm$ 1.89
70-79	225	55.11 $\pm$ 6.04	24.20 $\pm$ 3.09	121	37.27 $\pm$ 3.84	16.48 $\pm$ 1.98
≥ 80	188	52.36 $\pm$ 6.16	22.62 $\pm$ 3.10	65	35.47 $\pm$ 3.85	15.53 $\pm$ 2.10
All	1411	57.95 $\pm$ 7.11	26.22 $\pm$ 3.89	960	39.43 $\pm$ 4.47	17.82 $\pm$ 2.46

Table 4: Relative total and appendicular lean mass (relative to height; kg/m²) for men and women by ten-year age group and for the full age range (20-93 years; displayed as mean $\pm$ standard deviation)

Age group	Men			Women		
	n	Relative total lean mass	Relative appendicular lean mass	n	Relative total lean mass	Relative appendicular lean mass
20-29	180	18.45 $\pm$ 1.67	8.67 $\pm$ 0.90	176	14.89 $\pm$ 1.50	6.84 $\pm$ 0.80
30-39	194	19.11 $\pm$ 1.74	8.92 $\pm$ 0.95	132	15.00 $\pm$ 1.33	6.83 $\pm$ 0.74
40-49	203	19.43 $\pm$ 1.68	8.96 $\pm$ 0.93	161	14.97 $\pm$ 1.22	6.82 $\pm$ 0.68
50-59	215	19.32 $\pm$ 1.56	8.77 $\pm$ 0.79	159	15.06 $\pm$ 1.30	6.84 $\pm$ 0.72
60-69	206	19.29 $\pm$ 1.59	8.53 $\pm$ 0.79	146	15.04 $\pm$ 1.27	6.66 $\pm$ 0.64
70-79	225	18.74 $\pm$ 1.55	8.22 $\pm$ 0.82	121	14.93 $\pm$ 1.42	6.60 $\pm$ 0.76
≥ 80	188	18.02 $\pm$ 1.73	7.78 $\pm$ 0.88	65	14.74 $\pm$ 1.35	6.45 $\pm$ 0.78
All	1411	18.93 $\pm$ 1.71	8.55 $\pm$ 0.94	960	14.96 $\pm$ 1.34	6.75 $\pm$ 0.74

Table 5: Prevalence of relative appendicular lean mass within defined T-score categories* displayed by ten-year age group for men and women.

Age group	Men (n [%**])			Women (n [%**])		
	<-2.0	-2.0 to -1.0	>-1.0	<-2.0	-2.0 to -1.0	>-1.0
20-29	1 (0.6)	37 (20.6)	142 (78.9)	3 (1.7)	21 (11.9)	152 (86.4)
30-39	2 (1.0)	24 (12.4)	168 (86.6)	3 (2.3)	10 (7.6)	119 (90.2)
40-49	1 (0.5)	23 (11.3)	179 (88.2)	1 (0.6)	20 (12.4)	140 (87.0)
50-59	0 (0.0)	27 (12.6)	188 (87.4)	2 (1.3)	20 (12.6)	137 (86.2)
60-69	5 (2.4)	37 (18.0)	164 (79.6)	1 (0.7)	23 (15.8)	122 (83.6)
70-79	15 (6.7)	62 (27.6)	148 (65.8)	5 (4.1)	26 (21.5)	90 (74.4)
≥80	30 (16.0)	74 (39.4)	84 (44.7)	4 (6.2)	18 (27.7)	43 (66.2)
All	54 (3.8)	284 (20.1)	1073 (76.0)	19 (2.0)	138 (14.4)	803 (83.6)

* <-2.0, relative appendicular lean mass (ALM) more than two standard deviations (SD) below the young adult reference mean; -2.0 to -1.0, relative ALM equal to or between one or two SD below the young adult reference mean; >-1.0, relative ALM less than one SD below the young adult reference mean

** percentages may not add up to 100 due to rounding error

Table 6: Constant values, regression coefficients* and adjusted coefficients of determination (R^2) for linear regression models for absolute total and appendicular lean mass (kg) for men (n=1411) and women (n=960). Data represent univariable associations with (i) age (years) (ii) weight (kg) and (iii) height (cm) and (iv) multivariable parsimonious models.

	constant	age_c**	(age_c**) ²	weight_c**	(weight_c**) ²	height_c**	(height_c**) ²	adjusted-R ² (%)
Men								
Total lean mass								
(i)	59.53192	-0.1322527	-0.0041468	-	-	-	-	16.25
(ii)	57.95239	-	-	0.4562362	-	-	-	62.95
(iii)	57.95239	-	-	-	-	0.6590965	-	45.58
(iv)	58.51438	-0.0535287	-0.0014754	0.3486079	-	0.3177023	-	76.49
Appendicular lean mass								
(i)	26.93457	-0.0991644	-0.0018647	-	-	-	-	26.38
(ii)	26.38929	-	-	0.233327	-0.0010788	-	-	54.03
(iii)	26.22432	-	-	-	-	0.3637665	-	46.36

(iv)	26.53533	-0.0605608	-0.0004982	0.1751305	-0.0007928	0.1545895	-	75.64
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Women

Total lean mass

(i)	39.9389	-0.0742311	-0.0014391	-	-	-	-	11.86
(ii)	39.43031	-	-	0.2372331	-	-	-	46.88
(iii)	39.4303	-	-	-	-	0.413477	-	38.72
(iv)	39.43031	-0.0236117	-	0.192334	-	0.2745648	-	66.96

Appendicular lean mass

(i)	18.10326	-0.0472523	-0.0008143	-	-	-	-	15.46
(ii)	17.81548	-	-	0.1361979	-	-	-	51.11
(iii)	17.81548	-	-	-	-	0.2231418	-	37.29
(iv)	17.81548	-0.0224381	-	0.1136616	-	0.1302927	-	70.91

* all regression coefficients are significant at the level of $P \leq 0.001$

** *c* centred; the mean age, weight and height was subtracted from these variables before they were included in regression models (the mean age, weight and height for men and women, respectively was 55.5 and 51.2 years; 82.0 and 69.4 kg; and 174.8 and 162.3 cm)

Fig. 1 The association between age and appendicular (ALM) and total lean mass (LM) for men (a and b) and women (c and d). Regression line (solid) and 95% prediction interval (dashed), regression equations (age has been centred around the mean of 55.5 years for men and 51.2 years for women) and adjusted R^2 values shown

Fig. 2 The association between height and appendicular (ALM) and total lean mass (LM) for men (a and b) and women (c and d). Regression line (solid), 95% prediction interval (dashed), regression equations (height has been centred around the mean of 174.8 cm for men and 162.3 cm for women) and adjusted R^2 values shown

Fig. 3 The association between weight and appendicular (ALM) and total lean mass (LM) for men (a and b) and women (c and d). Regression line (solid), 95% prediction interval (dashed), regression equations (weight has been centred around the mean of 82.0 kg for men and 69.4 kg for women) and adjusted R^2 values shown

The authors have stated that they have no conflict of interest.