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Original Article

Relationship of body anthropometric measures with skeletal muscle mass and strength in a reference cohort of young Finnish women

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Abstract

Objectives: 1) To study if limb length explains variability in appendicular and total muscle mass better than height and 2) if muscle mass adjusted for limb length rather than height correlates better with grip and knee extension strength. **Methods:** 400 healthy women aged 20-40 were recruited as a reference population. Body composition, limb length, grip strength and knee extension strength were measured. New relative muscle mass indexes were computed by adjusting upper limb muscle mass for upper limb length (ULRSMI) and lower limb muscle mass for lower limb length (LLRSMI). **Results:** Height correlated strongest with all muscle mass measures. Height had the highest R^2 values for predicting variability in appendicular skeletal muscle mass (0.33), upper limb skeletal muscle mass (0.20), lower limb skeletal muscle mass (0.34) and total skeletal muscle mass (0.36). Correlation of relative skeletal muscle mass index (RSMI) with grip and knee extension strength (r=0.47 and 0.43) was higher when compared with correlation of ULRSMI and LLRSMI with these measures. **Conclusion:** Compared to limb length, height correlates better with regional and total muscle mass. Muscle mass adjusted for height correlates better with grip strength and knee strength when compared with muscle mass adjusted for limb length.

Keywords: Muscle Mass, Muscle Strength, Muscle Mass Indexes, Anthropometry, Reference Population

Introduction

Multiple indexes have been devised for describing the relative adiposity and muscularity in human beings. Most common index in this regard is the body mass index (BMI). The idea behind this index was that the weight scales to the square of height (Quetelet's index= Weight/Height^2)[1]. The BMI is a good index for relative adiposity but it is prone to classifying highly muscular people as obese or overweight[2].

With the advent of Dual X-Ray Absorptiometry, it became possible to reliably and inexpensively measure regional muscle mass[3]. In 1990, Valantlie and colleagues suggested that height normalized indexes of regional body composition measures could be used in a similar way as the BMI[4]. Using the same principle, a relative index for muscularity (leanness) was created by Baumgartner and colleagues[5]. The relative skeletal muscle mass index (RSMI), was calculated as appendicular skeletal muscle mass (ASM) per square of height (ASM/height^2). Multiple powers of height (height, height^2, height^3...) were tested as denominators in the equation and ASM/height^2 was found to have the least correlation with height. This index was tested and low score on this index was associated with multiple disability outcomes in men and women. RSMI, along with multipe other indexes like skeletal muscle index (SMI)[6,7] is now widely used to for diagnosis of Sarcopenia, which is defined as an accelerated loss of muscle mass with aging[8].

The height based indexes however do not consider that long bone length and height do not scale proportionately. Limb length to height proportions are different between taller and shorter individuals with taller individuals having

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larger relative limb size[9]. Keeping this in mind, adjusting muscle mass for height might overestimate the muscle mass for people with relatively longer limbs and underestimate it for people with relatively shorter limbs.

One possible way to address this is to adjust muscle mass for limb length instead of height. There have been no studies comparing limb length and height for their association with appendicular and total skeletal muscle mass, and if indexes that adjust appendicular muscle mass based on limb length correlate better with muscle strength. With the present study, our aim was to see if these body anthropometric measures (BAMs) are suitable alternatives to height for adjusting appendicular skeletal muscle mass.

Materials and methods

Study population

The study population (Kuopio sarcopenia reference population, KSRP) comprised of 400 young healthy females living in Kuopio, Eastern Finland. The population was recruited using electronic and conventional paper flyer forms to invite the students and staff of University of Eastern Finland and Kuopio University Hospital to participate in the study. Following eligibility criteria were set for the participants: 1) age 20-40 years 2) not currently pregnant 3) no chronic diseases or continuous medication 4) no orthopedic or other major implants within the body 5) no oophorectomy. Compliance to these criteria was assured by trained study group nurses prior to the start of measurements. Informed consent for the study was obtained from all the participants. The study was conducted in accordance with the ethical principles stated in the Declaration of Helsinki and the study protocol was approved by the ethical committee of the University of Eastern Finland and Kuopio university hospital. Study recruitment was planned in order to recruit participants in equally distributed quartiles (20-25 years: n=100, 25-30 years n=100, 30-35 years: n=100, 35-40 years: n=100. The recruitment and measurements took place between 2011 and 2014. Two cases were excluded from the final analysis because their upper limb was partially outside the DXA scanning field. Once case was excluded because of missing grip strength data.

Total body DXA and muscle strength measurements

Total body dual energy x-ray absorptiometry (TB-DXA) measurements were carried out by trained study nurses. The TB-DXA measurements were performed between 2011 and 2014 in Kuopio Musculoskeletal Research Unit, University of Eastern Finland, Kuopio, Finland. 204 measurements were performed with Lunar Prodigy DXA and 196 measurements with Lunar iDXA with the imaging and analysis protocols provided by the manufacturer (Lunar Co, Madison, WI, USA). Older prodigy system was replaced with Lunar iDXA during the follow-up. In a previous study published by our study group, cross calibration coefficients were calculated for both the scanners, using total body scans from 55 women[10]. Subjects were scanned with both scanners during the same day and using Altman's regression, coefficients were calculated to make muscle mass measures obtained by Prodigy bone densitometer comparable with iDXA. We used these coefficients to adjust the lean mass results obtained by the Prodigy bone densitometer accordingly. Quality control and calibration was carried out according to the instructions provided by the manufacturer. DXA scans were analyzed through software provided by the manufacturer (Encore v14.00) which automatically delineates regions of interest (ROIs) based on an inbuilt algorithm. Total skeletal muscle mass (TSM) and muscle mass for each limb was computed by the software based on these ROIs. Upper limb skeletal muscle mass (USM) and lower limb skeletal muscle mass (LSM) were obtained by adding muscle mass from both the upper and lower limbs respectively. Appendicular skeletal muscle mass (ASM) was obtained by combining USM and LSM.

The grip strength of dominant hand was measured with handheld dynamometer (Jamar; Saehan corporation, Masan, Korea) and reported in newtons (N). Three measurements were recorded in a sitting position, arm parallel and forearm flexed at 90 degrees to the body, with hand in a mid-prone position. An average of three readings was used as grip strength for purpose of analysis. Leg extension strength of both legs was measured three times for each leg, with knee extensor bench (Metitur, Finland) and reported in newtons. Average knee extension strength was regarded as an average of all six consecutive measurements. Weight of each participant was measured with a calibrated scale (Philips Type HF 351/00) and reported in newtons. Height was measured with a calibrated stadiometer (Harpenden stadiometer), and reported in cm.

Limb length measurement

Direct anthropometric measures were not available for the cohort so limb length measurement was carried out using the total body scans taken with Lunar Prodigy DXA and Lunar iDXA and using linear pixel count method. The validity of this method for calculating bone length has been demonstrated previously[11]. A reference line of 30 cm was drawn on the scans using Lunar iDXA software and the scans were imported into "webplotdigitizer" software[12]. The reference line was used to calibrate the scale. Length of upper arm was measured as a line from the upper edge of the head of humerus to the joint space between humerus and ulna. Lower arm length was measured from the elbow joint space to the distal end of the radius. Upper leg length was measured from the top edge of the greater trochanter to the joint space between femur and tibia. Lower leg length was measured from the knee joint space to the talocrural joint. Intertrochanteric distance (ITD) was measured by drawing a line between the topmost edges of both the greater trochanters.

The length of upper arm and forearm was taken as upper limb length (ULL). Length of upper leg and lower leg was added to calculate lower limb length (LLL). Sitting height (SH) was computed by subtracting LLL from height.

Upper limb length and grip strength of dominant arm were used in the analysis. For Leg extension strength, average strength of right and left leg extension was used in the analysis along with an average length of both lower limbs.

Limb length based indexes

RSMI and SMI were calculated using following formulas
RSMI = appendicular skeletal muscle mass/ height^2
SMI = (total skeletal muscle mass / total body weight) x 100

Upper limb relative muscle mass index (ULRSMI) and lower limb relative muscle mass index (LLRSMI) were calculated by dividing the mass of upper and lower limb by the square of their respective mean limb length. To decide which power of height should be used as a denominator, multiple powers of upper and lower limb length were tested to find the one least correlated with height. Indexes having ULL and LLL squared (ULL^2 and LLL^2) as denominators were found to have the least correlation with height, showing that they were least influenced by the effects of stature. The indexes were further multiplied by 10^3 in order to make them easier to interpret.
ULRSMI = (upper limb muscle mass / upper limb length^2) x 10^3
LLRSMI = (lower limb muscle mass / lower limb length^2) x 10^3

Statistical analysis

Statistical analysis was carried out using Statistical Package for the Social Sciences (SPSS v. 21). Bivariate correlation was used to study the relationship between the anthropometric measures and muscle mass measures. Linear regression analysis was carried out using muscle mass measures (ASM, USM, LSM and TSM) as dependent variables and BAMs (Height, ULL, LLL and ITD) as independent variables for their ability to predict these dependent variables

Limb length based indexes' correlation with leg extension and grip strength was also compared to respective correlation with RSMI and SMI. Steiger's Z test for comparison of correlated correlations was used to compare the strength of correlations.

Results

Baseline characteristics of the study population are given in Table 1 which includes the mean reference values for all the muscle mass indexes (RSMI, ULRSMI, LLRSMI) along with their standard deviation (Table 1).

Of all the body anthropometric measures, height showed the strongest correlation with ASM, USM, LSM and TSM when compared to ULL, LLL, ITD and SH (Table 2). Using Steiger's Z test for comparison of correlated correlations, correlations of muscle mass measures with height were compared with their correlations with other BAMs. Only the correlation between ITD and USM was comparable to correlation between height and USM (Steiger's Z test, z= -1.24, p=0.21).

In linear regression analysis for prediction of muscle mass using different body anthropometric measures, height gave the highest R squared value for predicting total and regional muscle mass (R^2=0.33, 0.20, 0.34 and 0.36 for ASM, USM, LSM and TSM respectively). Using ULL, LLL, ITD and SH as independent variables did not improve the R squared value of the linear regression equation (Table 3).

RSMI, ULRSMI and LLRSMI were all correlated with grip strength and leg extension strength (Table 4.). Correlations of RSMI with grip strength (Steiger's Z test for RSMI, LLRSMI and grip strength correlation, z=5.97, p<0.001, 95% CI) and leg extension strength (Steiger's Z test RSMI, LLRSMI and leg extension correlation, z=4.73, p<0.001, 95% CI) were not comparable with similar correlations with LLRSMI.

The correlation of ULRSMI with both grip strength (Steiger's Z for RSMI, ULRSMI and grip strength correlation, z=0.13, p=0.89, 95% CI) and leg extension strength (Steiger's Z for RSMI, ULRSMI and leg extension strength correlation, z=0.26, p=0.79, 95% CI) was equal to similar correlation between these muscle strength measures and RSMI. SMI showed no significant correlation with grip strength and leg extension strength.

Table 1. Population characteristics of the study group (n=397).

	Mean (SD)
Anthropometric/body composition measures	
Height (cm)	166.6 (5.9)
Weight (N)	626.7 (104.7)
Appendicular skeletal muscle mass (kg)	18.8 (2.5)
Upper limb skeletal muscle mass (kg)	4.3 (0.68)
Lower limb skeletal muscle mass (kg)	14.5 (2.0)
Total skeletal muscle mass (kg)	41.8 (4.9)
Upper limb length (cm)	52.30 (2.7)
Lower limb length (cm)	78.52 (3.9)
Intertrochanteric distance (cm)	26.70 (1.3)
Sitting height (cm)	88.0 (3.2)
Muscle strength measures	
Handgrip strength (N)	354.4 (52.6)
Leg extension strength (N)	487.7 (98.4)
Muscle mass indexes	
RSMI	6.76 (0.8)
SMI	66.48 (7.1)
ULRSMI	1.57 (0.24)
LLRSMI	2.36 (0.29)

Discussion

The purpose of our study was to investigate if relative muscle mass indexes should be calculated by adjusting muscle mass for height or other anthropometric measures such as limb length, intertrochanteric distance or sitting height. In our results, out of all the body anthropometric measures compared, height showed the highest correlation

Table 2. Pearson's correlation coefficients between BAMs, body composition and strength measures.

	Appendicular muscle mass (ASM)	Upper limb muscle mass (USM)	Lower limb muscle mass (LSM)	Total skeletal muscle mass (TSM)
Height	0.57	0.45	0.58	0.60
Upper limb length	0.47	0.38	0.48	0.49
Lower limb length	0.49	0.38	0.50	0.49
Intertrochanteric distance	0.46	0.40†	0.45	0.50
Sitting height	0.43	0.35	0.44	0.48

**All correlations in the table were significant at p <0.001 level. †The correlation index for Intertrochanteric distance with USM was equal in comparison, with correlation between height and USM (Steiger's Z test).*

Table 3. linear regression R square values for prediction of ASM, USM, LSM and TSM (kg) using different BAMs as independent variables.

	ASM	USM	LSM	TSM
Height (m)	0.33 (25.3)	0.20 (5.2)	0.34 (20.0)	0.36 (50.2)
Upper limb length (m)	0.23 (46.5)	0.14 (9.6)	0.23 (36.8)	0.24 (90.8)
Lower limb length (m)	0.24 (32.3)	0.14 (6.5)	0.25 (25.8)	0.24 (61.4)
Intertrochanteric distance (m)	0.21 (89.4)	0.16 (20.4)	0.21 (69.0)	0.25 (185.0)
Sitting height (m)	0.19 (34.6)	0.12 (7.4)	0.19 (27.19)	0.23 (73.0)

**The results are presented as R^2 (B).*

Table 4. Person's correlation coefficients for correlation of muscle mass indexes with grip strength and leg extension strength.

	RSMI	LLRSMI	ULRSMI	SMI
Grip strength (N)	0.47*	0.33*	0.46*†	0.06
Leg extension strength (N)	0.43*	0.33*	0.39*†	0.05

** Correlation statistically significant at p <0.001 level. †These correlations of relative muscle mass indexes with muscle strength measures were equal to the correlation of RSMI with corresponding muscle strength measures (Steiger's Z test).*

with all skeletal muscle mass measures. Only the correlation coefficient between intertrochanteric distance and upper limb muscle mass was comparable to the correlation coefficient for height and upper limb muscle mass. Based on these results, height is still a preferable anthropometric measure for adjusting muscle mass, due to ease of measurement and its better correlation with all the other regional muscle mass measures. The results from linear regression analysis showed that when all BAMs are compared, height predicts variability in regional and total muscle mass better (Table 3). Using height as the dependent variable gave the highest r squared values for all the muscle mass measures.

The indexes of relative muscle mass were computed by adjusting appendicular, upper limb and lower limb muscle mass by square of height, upper limb length and lower limb length respectively. Upper limb muscle mass adjusted for upper limb length, correlated with grip strength and leg extension strength, equally as good as appendicular muscle mass adjusted for height (RSMI) but did not show any significant improvement. Lower limb muscle mass adjusted for lower limb length was significantly correlated with grip strength and leg extension but the correlation was lower than that of RSMI with these measures. SMI did not show any significant correlation with muscle strength measures in our cohort.

The indexes for computing relative muscularity or adiposity are based on principle that the muscle mass or adipose tissue must be adjusted according to stature when comparing individuals of different sizes[13]. Most commonly, these indexes are adjusted for height (BMI, RSMI) or weight (SMI)[14]. Keeping in mind the differences in how limb growth scales with growth in height, we investigated if limb length accounts for more variability in appendicular muscle mass than height. The rationale was that limb length adjusted muscle mass index would predict functional outcomes like grip strength and quadriceps strength better.

A limitation of our study is that height was directly measured using a stadiometer while other BAMs used were measured from DXA scans using linear pixel count method. Even though the validity of this method has been ascertained in a previous study by another group[11], we did not have gross anthropometric measures for limb length to ascertain the reproducibility of this method in our lab. Sitting height was derived by subtracting lower limb length from height. Using known length components to derive length of new segments, though not as precise as direct measurement, is still a valid method[15]. Also, the results of this study are limited to women and it would be more complete if data was also obtained for men. Another possible approach to study this question is to observe if a limb length adjusted muscle mass index predicts frailty related outcomes (incident falls, fractures, disability) better than RSMI in a cohort of elderly people.

Conclusion

When comparing height, limb length and inter trochanteric distance, height better explains the variability in appendicular and total muscle mass. The most commonly used index of relative muscle mass, RSMI (Appendicular muscle mass adjusted for height), had highest correlation with grip strength and knee extension strength. When compared with RSMI, ULRSMI (upper limb muscle mass adjusted for upper limb length) and LLRSMI (lower limb muscle mass adjusted for lower limb length), did not correlate better with grip strength and knee extension strength.

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