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Title: Development of an anthropometric prediction model for fat free mass and muscle mass in elite athletes

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Running Title: Anthropometric models for lean mass tissues

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ABSTRACT

The monitoring of body composition is common in sports given the association with performance. Surface anthropometry is often preferred when monitoring changes for its convenience, practicality and portability. However, anthropometry does no provide valid estimates of absolute lean tissue in elite athletes. The aim of this investigation was to develop anthropometric models for estimating fat free mass (FFM) and skeletal muscle mass (SMM) using an accepted reference physique assessment technique. Sixty-four athletes across eighteen sports underwent surface anthropometry and dual-energy X-ray absorptiometry (DXA) assessment. Anthropometric models for estimating FFM and SMM were developed using forward selection multiple linear regression analysis and contrasted against previously developed equations. Most anthropometric models under review performed poorly compared to DXA. However, models derived from athletic populations such as the Withers equation demonstrated a stronger correlation with DXA estimates of FFM (r=0.98). Equations that incorporated skinfolds with limb girths were more effective at explaining the variance in DXA estimates of lean tissue (Sesbreno FFM ($R^2 = 0.94$) and Lee SMM ($R^2 = 0.94$) models). The Sesbreno equation could be useful for estimating absolute indices of lean tissue across a range of physiques if an accepted option like DXA is inaccessible. Future work should explore the validity of the Sesbreno model across a broader range of physiques common to athletic populations.

INTRODUCTION

The assessment of body composition is common in sports given the association with performance. In many elite sport programs, fat mass (FM) is monitored given the negative implications of excessive fat on power to weight ratio, hydrodynamic drag, and performance scores (Claessens et al., 1994; Claessens et al., 1999 & Siders et al., 1993). However, indices of lean tissue may also have an important association with competitive success. (Slater et al., 2005 & Sanchez-Munoz, et al., 2017). It is therefore important to examine body composition in elite athletes to assess their relationship with performance in the field.

Dual Energy X-Ray Absorptiometry (DXA) is increasingly integrated into the monitoring of athletic populations to provide timely information on both absolute and relative whole body and regional body composition, plus bone health (Meyers et al., 2013). However, without careful adherence to best practice guidelines, DXA precision error may fall beyond expected body composition changes observed over a training period (Zemski et al., 2018a). Additionally, radiation health regulations and/or equipment inaccessibility may restrict the use of DXA, precluding frequent monitoring in some regions. This would limit the potential use of DXA to better inform dietary and/or training interventions based on body composition changes observed. Therefore, a complementary method like surface anthropometry would be useful.

Surface anthropometry is frequently used for monitoring body composition in athletes due to its portability, cost effectiveness and extremely high precision (Meyer et al., 2013). A number of skinfold equations have been validated to estimate body fat percent (BF%) (Forsyth et al., 1973, Reilly et al., 2009; Thorland et al., 1984 & Withers et al., 2009), and through simple calculation, absolute FM and fat free mass (FFM; overall mass excluding fat mass). Some practitioners apply this approach of estimating FFM in athletes in the daily training environment. However, few, if any of these skinfold equations have been validated to quantify body composition change (Cisar et al., 1989; Silva et al., 2009 & Wilmore et al., 1970), and concerns have been raised about inference of FFM from an indirect measure of subcutaneous FM (Martin et al., 1990). An alternative approach would be to include a wider range of anthropometric measures as applied in the Drinkwater fractionation model to estimate body composition (Drinkwater et al., 1980).

The Drinkwater four-way fractionation model uses the unisex phantom model to partition total body mass into four compartments - FM, skeletal muscle mass (SMM; intramuscular adipose tissue included), bone mass and residual mass (Drinkwater et al., 1980). This model may offer some advantages for estimating FFM, lean body mass (LBM; overall mass excluding fat and bone masses) and SMM compared to those exclusively derived from skinfolds. However, the effort to optimize physique for performance has lead to a wide range of physique characteristics in elite sports. This may limit the suitability of an anthropometric equation for evalutating body composition across a range of sports. For instance, the fractionation model may not be generalizable to muscular athletes as marked variance between total fractionated mass and scaled mass have been observed in muscular individuals (Keogh et al., 2007). Therefore, other models need to be considered for athletes across a range of physiques.

The present study aimed to: 1) compare the ability of selected anthropometric models to evaluate lean tissues in elite athletes compared to DXA; & 2) develop an anthropometric prediction model for FFM and SMM in elite Canadian athletes.

METHODS

Recruitment

Sixty-five athletes, 17 years of age or older, were recruited through emails sent to sport science staff across the Canadian Olympic and Paralympic Sport Institute Network and National Sport Organizations as well as poster marketing throughout the Canadian Sport Institute Ontario between October 2017 and October 2018. Athletes were eligible for inclusion if they competed internationally for Canada at a sport event hosted by an International Federation on the Olympic program between October 2016 and October 2018. Athletes were provided with details on the nature of the study, and all participants provided written informed consent in accordance with the declaration of Helsinki. Ethics approval was obtained through the University of Stirling and the Canadian Sport Institute Ontario Research Ethics Committees.

Experimental Design

Data collected included athlete demographics, urinalysis, pregnancy testing (Golden Time, One Step, HCG Pregnancy Test 2.5mm strip) if female, anthropometry and DXA. Anthropometry and DXA testing were conducted back to back on the same day. Subjects were excluded from the study if they were >190cm tall. Female athletes were excluded if they were pregnant.

To minimize biological variability, all assessments were conducted in an overnight fasted (≥8 hours post-prandial), rested state following a low training volume day. Participants were instructed to maintain their usual dietary habits the day prior to testing, with the addition of 500ml of water at each eating occasion. To confirm hydration status, specific gravity of the first void urine sample on the morning of testing was assessed using an automated refractometer (Atago 4410 Digital

Urine Refractometer, Tokyo, Japan). Those who were hypohydrated, as defined by a USG >1.026 (Armstrong et al., 2010 & Rodriguez-Sanchez et al., 2015) were excluded.

Dual-Energy x-Ray Absorptiometry

The DXA (Lunar Prodigy, GE Healthcare, Madison, WI) was calibrated with phantoms as per manufacturer guidelines each day before measurement. All scans were conducted by the same bone densitometry technologist (ES), certified through the International Society of Bone Densitometry, with a within day repeated test-retest technical error of measurement of 0.4% for total lean and 1.5% for total fat mass. The USA (Combined NHANES (ages 20-30) / Lunar (ages 20-40)) Total Body Reference Population (v113) was used as the reference database with analysis performed using GE Encore version 13.60 software (GE, Madison, WI). The thickness mode was determined by the auto scan feature in the software and all safety protocols as per the institution's radiation safety protection plan were adhered to.

Athletes were asked to wear minimal clothing without metal zippers, tags, or studs and with all metal jewelry removed. Athletes were positioned according to protocols previously described (Nana et al., 2015). Athletes were centrally aligned on the scanning area with their head positioned in the Frankfort plane and with their feet placed in custom-made radio-opaque polystyrene foam blocks to maintain a constant distance of ~15cm between the feet. Similarly, the participants' hands were placed in shaped polystyrene foam blocks, so they would be in a mid-prone position with a consistent gap of ~3cm between the palms and trunk. Two Velcro straps were used to minimise any participant movement during the scan. One strap was secured around the ankles above the foot positioning pad and the other strap was secured around the trunk at the level of the mid forearms. All scans were analysed automatically by the DXA software, but all regions of interest were reconfirmed by the technician (ES) before being included in the subsequent statistical analysis.

Appendicular lean soft tissue (ALST) derived from DXA was used to estimate SMM via the Kim equation (Kim et al, 2002).

Surface Anthropometry

Full anthropometric profiles, including body mass, stretch stature, sitting height, skinfolds at eight sites, eleven girths, nine lengths and six breadths were landmarked and measured by an anthropometrist holding a level III accreditation from the International Society for the Advancement of Kinanthropometry (ISAK) (ES) with a technical error of measurement of ≤ 2.0% for sum of eight skinfolds and ≤ 1.0% for all other measures.

Sitting height and stretch stature were measured using a wall mounted stadiometer (Perspective Enterprises, Portage, Michigan, USA) with a precision of ± 1.0mm. Skinfolds was assessed using Harpenden calipers (Baty International, Burgess Hill, England). Girth measurements were undertaken using a flexible steel tape (Rosscraft, Surrey, BC, Canada). Body limb lengths were measured with a modified steel tape adapted with a segmometer (Rosscraft, Surrey, BC, Canada). The majority of breadths were measured with the Campbell 20 large sliding bone caliper (Rosscraft, Surrey, BC, Canada); biepicondylar breadths were measured with a Campbell 10 small sliding bone caliper (Rosscraft, Surrey, BC, Canada). Body mass was assessed in minimal clothing on a calibrated digital scale with a precision of ± 0.1 kg (Seca 876, Hamburg, Germany).

All measurements were made on the right side of the body using ISAK techniques previously described (Stewart et al., 2011). All measurements were undertaken in duplicate. If the difference between duplicate measures exceeded 5% for an individual skinfold or 1% for all other variables, a third measurement was taken after all other measurements were completed. The mean of duplicate or median of triplicate anthropometric measurements were used for all subsequent analyse.

The fractionation (Drinkwater & Ross, 1980) and multiple linear regression models (Withers et al, 1987, Lee et al., 2000 & Reilly et al., 2009) were used to estimate body composition through surface anthropometry (Table 1). The Siri equation (Siri, 1956) was used to convert body density to percent body fat for the Withers' equation (Withers et al., 1987). For both the Reilly (Reilly et al 2009) and Withers equations, FFM was calculated according to the following equation:

FFM (kg) = body mass (kg) – (body mass (kg) x body fat %/100).

Fractionated muscle, fat, bone, and residual masses were calculated as previously described (Drinkwater and Ross, 1980) and selectively combined to generate estimates of:

Fractionated FFM (kg) = fractionated SMM (kg) + fractionated residual mass (kg) + fractionated bone mass (kg)

Fractionated LBM (kg) = fractionated residual mass (kg) + fractionated SMM (kg)

The fractionated SMM and Lee equations (Lee et al., 2000) were used to predict SMM. ISAK landmarks were used to operate the Lee equation to better manage time limitations in the laboratory. The original landmarks for the Lee equation are approximately near 1cm of the ISAK landmarks for each input variable, thus the differences associated with technical error of measurement were assumed as minimal.

Statistical Methods

Statistical analyses were carried out using SPSS (SPSS v23.0; IBM Inc, Chicago, IL). Descriptive statistics are presented as mean (μ) ± standard deviation (SD). Differences in physique traits based on gender were investigated using independent t-tests. Box plots and Q-Q plots were used to identify any extreme outliers, with participants considered outliers if they were greater than two SD away from all somatotype classifications.

A least square regression analysis was used to assess the validity of fractioned FFM, fractionated LBM and fractionated SMM compared to DXA. The potential for any fixed bias was assessed by determining whether the intercept for the regression was different from zero. The slope of the regression line was used to identify proportional bias if it was different from one. Random error was quantified using the standard error of the estimate (SEE) from the regression. Predictive accuracy of the FFM, LBM and SMM equations were evaluated by calculating the mean 95% prediction interval (M95%PI). This interval represents the uncertainty of predicting the value of a single future observation.

Forward selection multiple regression analysis was performed using fractionated FFM and fractionated FM from the elite Canadian athlete data set to derive a prediction model of FFM and SMM for this population group. Data for the regression analysis conformed to the assumptions of homoscedasticity, independent and normally distributed and no multicollinearity.

RESULTS

Sixty-five athletes across eighteen sports including beach volleyball, track cycling and athletics, were recruited for the study. After preliminary statistical analysis, one athlete was removed from the final analysis as the subject was identified as an extreme outlier, leaving sixty-four participants. Full anthropometric and body composition characteristics are presented in Tables 2 and 3. Significant differences between male and female athletes were observed among bone breadths, upper body girths, upper limb girths and body composition parameters.

All anthropometric models for predicting FFM, LBM and SMM had a strong positive correlation with reference DXA measures (Table 4). The strength of correlation was similar amongst all anthropometric equations for FFM as well as between equations for SMM.

The slope, intercepts, standard error of the estimate and M95%PI for each anthropometric equation are listed in Table 4. Of all the FFM equations assessed, the random error and magnitude of the M95%PI were lowest with the Withers' equation. All equations overestimated FFM compared to DXA and varied in proportional bias. The degree of proportional bias was higher in female athletes. When examining the various fractionation models, the random error improved from FFM to SMM in all participants and across genders. Amongst the fractionated models, fractionated LBM had the highest random error, and M95%PI in all participants. The Withers' equation had the lowest M95%PI amongst the FFM models, whereas the fractionated SMM equation had the lower M95%PI between the SMM models in all participants. Between the fractionated and Lee equations for predicting SMM, the fractionated equation had a lower random error in all participants and female athletes. The Lee equation had the lowest fixed and proportional biases in all participants. The fractionated equation overestimated SMM in all subjects while showing proportional bias.

Forward selection multiple regression analysis was used on 64 athletes to derive 2 novel equations (Table 5). The equations are:

Sesbreno FFM (kg) = 3.397 + (0.975 x Fractionated Fat Free Mass (kg)) – (0.576 x Fractionated Fat Mass (kg))

Sesbreno SMM (kg)= -2.485 + (1.058 x Fractionated Skeletal Muscle Mass (kg)) – (0.235 x Fractionated Fat Mass (kg))

Using the combination of fractionated FFM and FM, the Sesbreno model explained 94% of the variance in DXA FFM compared to the Withers and Reilly equations, which explained 5% and 32% of the variance, respectively. When using the combination of fractionated SMM and FM, the Sesbreno model explained 93% of the variance in DXA SMM, while the Lee equation explained 94%.

DISCUSSION

The primary finding of this investigation is that most anthropometric models for estimating absolute indices of lean tissue performed poorly compared to DXA. The more effective options were the Lee and novel Sesbreno equations, most likely because they were derived from populations similar to the one being investigated. In this study, the highest correlation with estimates of FFM from DXA was the Withers equation. This could be a function of using a female athlete derived equation on a sample that was proportionally high in female athletes. This would be consistent with work involving elite football athletes where equations derived from athletic populations were superior at estimating absolute fat mass compared to estimates from general population (Reilly et al., 2009). However, given morphological optimization, athletic physiques may vary markedly and as such, sport specific regression equations may need to be derived. For instance, the Reilly and Withers equations were derived from athletic populations, and both demonstrated a greater tendency to deviate from DXA at the higher end of the range of estimates of FFM. This parallels an earlier finding that described greater differences in total body mass between the anthropometric fractionation model and the weight scale in more muscular powerlifters (Keogh et al., 2007). Therefore, it may be important to account for the athletic population when selecting an anthropometric model for estimating absolute indices of lean tissue, but attention to the validity of the input variables may also be necessary.

The anthropometric models that complemented skinfold data with girth measurements, indirect measures of lean tissues, were more suitable for estimating absolute indices of lean tissue. For instance, the Sesbreno and Lee equations incorporated indirect measures of lean tissue, and both performed similarly for estimating SMM. This confirms prior research involving human cadavers that revealed a strong correlation between corrected limb girths and SMM (Martin et al., 1990). Moreover, the Sesbreno model for estimating FFM was superior at explaining the variance in DXA estimates of FFM compared to the Withers and Reilly skinfold equations. It suggests that using a wide range of physique traits, and not skinfold alone, are important for modeling indices of lean tissue in athletes. Learning the value of combining athletic population characteristics with indirect measurements of lean tissues for the development of anthropometric models, may help create practical and more suitable resources for practitioners to manage evaluations in athletic populations.

Absolute estimates of lean tissue may be necessary for a range of reasons. While quantifying absolute change in LM in response to training and/or nutrition is commonly advocated, estimates of FFM may be necessary to interpret data related to resting metabolic rate (RMR) for the assessment of energy availability (EA). For instance, the Sesbreno FFM model may be used to operate the Cunningham equation (Cunningham, 1980) for estimating predicted RMR. When interpreting a simulated calculation of predicted RMR on the smallest athlete in this investigation, the agreement between DXA and the Sesbreno model (+0.8% difference) was better compared to the Withers (+3.8%) and Reilly equations (+2.1%). Using the Sesbreno model may reduce additional variance observed from using the skinfold equations and limit the odds of overestimating cases of suppressed RMR from the assessment of measured:predicted RMR for the detection of low energy availability. The Sesbreno model is likely appropriate for a range of athlete sizes, but its suitability for very muscular athletes (FFM index >23.4 kg/m^2) and those standing taller than 190cm warrants investigation. If DXA is inaccessible, well selected anthropometric models could allow practitioners to operate broader assessments for managing athlete care, but may not have the precision to track small but important changes in response to training and/or diet. The ability of the Sesbreno equation to accurately track changes in body composition warrants investigation. However, before selecting any model for evaluating body composition, it is important to recognize the limitations our investigation to inform assessment outcomes.

Several decisions on study design impacted the assessment of indices of lean tissue. First, DXA precision error is recognised to be impacted by an array of factors, including client presentation (Nana et al., 2015 & Rodriguez-Sanchez et al., 2015). While guidance was provided to athletes on ways of minimising this, responsibility for this was left with the athletes. However, upon waking indices of hydration status confirmed all athletes presented in a euhydrated state. Second, three athletes with titanium bone plates, or rods and screws inserted in the upper or lower limb, were included in the study analysis. Titanium bone inserts, such as hip replacement devices have shown to increase the risk of overestimating FFM when using DXA (Madsen et al., 1999). However, the implants in our subjects were considerably smaller leading to assume that the degree of inaccuracy was lower than reported. Third, the Kim equation was used for estimating SMM from DXA results. The Kim equation required a DXA estimate of ALST, with subject's hands in the prone position. Our subjects' were in the mid-prone position to manage best practice protocols for body composition testing (Nana et al., 2015). A second scan was avoided to better manage time restraints and exposure to radiation. Although variations in hand position could result in a statistical difference in lean mass estimate of the limbs, the absolute difference was expected to be small (<0.1kg) (Thurlow et al., 2017). Finally, the original landmarking protocol for the Lee equation was replaced with the ISAK protocol to manage restraints on time. It is unclear if the performance of the Lee equation was a function of the regression model and/or errors associated with the estimates of indirect measures of lean tissue. However, the variance in landmark points between the Lee and ISAK protocols was small and unlikely resulted in a meaningful difference in girths and skinfolds measurements (Daniel et al., 2010 & Humes et al., 2008). These incidences provide a reminder that avoiding protocols specified in the original research introduces noise in the assessment.

In conclusion, carefully selected anthropometric models could be useful for estimating indices of lean tissue if other assessment methods are inaccessible. Ideally, the model should be derived from a similar population and from indirect measures of lean tissue. It is also advocated that the practitioner uses landmarks consistent with the original study to minimize noise. Compared to skinfold anthropometric models assessed, the novel Sesbreno equation may offer a suitable option for estimating absolute indices of lean tissue to undertake broader assessments such as the interpretations of resting metabolic rate or energy availability. Future work should explore the validity of the Sesbreno model across a broader range of physiques common to athletic populations.

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Table 1. Anthropometric regression models assessed in this investigation

Authors	**Reference Assessment**	**Equation Input Variables**
Drinkwater & Ross, 1980	Anthropometry	Fractionated FFM (kg) = standing height, biacromial breadth, biiliocristal breadth, transverse chest breadth, anterior-posterior chest depth, bi-epicondylar femur, bi-epicondylar humurus, wrist girth, ankle girth, corrected relax arm girth, forearm girth, corrected chest girth, corrected thigh girth and corrected calf girth.
		Fractionated SMM (kg) = standing height, corrected relax arm girth, forearm girth, corrected chest girth, corrected thigh girth and corrected calf girth.
		Fractionated FM (kg) = standing height, triceps skinfold, subscapular skinfold, supraspinale skinfold, abdominal skinfold, front thigh skinfold, and medial calf skinfold.
Withers et al., 1987	Hydrodensitometry	BF (%) = bicep skinfold, triceps skinfold, subscapular skinfold, supraspinale skinfold, abdominal skinfold, front thigh skinfold, and medial calf skinfold.
Reilly et al., 2009	DXA	BF (%) = triceps skinfold, mid-thigh skinfold and medial calf skinfold
Lee et al., 2000	MRI	SMM (kg) = standing height, corrected arm girth, corrected thigh girth, corrected calf girth, gender, age and race

Table 2. Anthropometric characteristics of the elite Canadian athletes

Variables		**All N = 64**		**Male N = 20**		**Female N = 44**		**p**
		µ± SD	**Range**	**µ± SD**	**Range**	**µ± SD**	**Range**	**value**
Basics	Standing Height (cm)	174.3±6.9	156.9-188.3	179.6±5.0	171.5-188.3	171.9±6.3	156.9-182.9	0.000
	Body Mass (kg)	70.9±9.9	49.1-96.6	79.4±9.5	60.9-96.6	67.1±7.4	49.1-80.8	0.000
Skinfolds (mm)	Sum of 8	82.5±29.9	34.9-183.4	68.2±35.0	34.9-183.4	87.8±25.5	36.4-167.5	0.008
Girths (cm)	Arm Relax	30.1±3.3	23.1-38.3	32.6±3.4	26.4-38.3	29.0±2.5	23.1-36.0	0.000
	Arm Flexed	31.4±3.4	25.0-39.9	34.7±3.3	29.1-39.9	30.0±2.2	25.0-36.7	0.000
	Forearm	26.6±2.5	22.4-33.8	29.1±2.5	24.6-33.8	25.5±1.4	22.4-28.4	0.000
	Wrist	16.0±1.0	14.3-19.2	17.1±1.0	15.2-19.2	15.6±0.6	14.3-16.8	0.000
	Mesosternale	94.4±6.9	80.0-112.5	101.5±6.0	89.8-112.5	91.2±4.4	80.0-103.4	0.000
	Mid Thigh	55.4±4.2	46.4-66.4	56.5±4.6	49.2-66.4	54.9±3.9	46.4-63.6	0.299
	Calf Maximum	36.7±2.1	31.5-42.6	37.3±2.1	34.5-42.6	36.4±2.0	31.5-41.0	0.154
	Ankle	22.4±1.3	19.1-22.4	23.2±1.3	20.9-25.7	22.0±1.1	19.1-24.2	0.003
Breadths (cm)	Bioacromial	39.2±2.2	34.8-46.5	41.3±1.8	38.9-46.5	38.2±1.7	34.8-41.9	0.000
	Biiliocristale	28.2±1.6	24.1-32.1	28.5±1.4	26.2-31.7	28.2±1.8	24.1-33.2	0.000

	Transverse Chest	28.7±2.2	25.5-34.3	31.1±1.8	27.0-34.3	27.8±1.9	25.5-35.4	0.000
	A-P Chest	18.4±1.8	14.2-22.4	20.1±1.5	17.1-22.4	17.8±1.8	14.2-25.2	0.000
	Humurus	6.8±0.5	5.8-7.9	7.3±0.4	6.3-7.9	6.5±0.3	5.8-7.2	0.000
	Femur	9.4±0.5	8.2-11.0	9.9±0.5	9.1-11.0	9.2±0.4	8.2-10.3	0.000

Data are Mean (μ) ± Standard Deviation (SD); Sum of 8 skinfolds=bicep, subscapcular, tricep, iliac, supraspinale, abdominal, front thigh and mid-calf; A-P = anterior-posterior.

Table 3. Physique characteristics of the elite Canadian athletes

Body Composition	Method	All N=64		Male N=20		Female N=44		p value
		μ±SD	Range	μ±SD	Range	μ±SD	Range	
Fat Free Mass (kg)	DXA	57.9±9.0	49.7-97.4	67.7±7.5	55.4-80.2	53.4±5.2	42.4-63.8	0.000
	Fractionation (1980)	60.4±9.0	43.7-77.9	70.3±6.9	56.3-77.9	55.9±5.6	43.7-67.3	0.000
	Withers (1987)	61.9±8.7	45.3-83.0	70.9±7.5	57.6-83.0	57.9±5.5	45.3-69.5	0.000
	Reilly (2009)	61.9±8.6	44.2-83.2	70.5±7.6	56.2-83.2	58.0±5.8	44.2-69.6	0.000
Lean Body Mass (kg)	DXA	54.8±8.7	39.8-76.5	64.2±7.3	52.6-76.5	50.5±5.0	39.8-60.6	0.000
	Fractionation (1980)	49.6±7.2	35.6-64.1	57.5±5.6	46.4-64.1	46.1±4.6	35.6-55.2	0.000
Skeletal Muscle Mass (kg)	DXA	29.6±5.6	19.8-43.3	35.6±5.0	27.1-43.3	27.2±3.7	19.8-36.8	0.000
	Fractionation (1980)	32.1±5.1	22.1-42.2	37.5±4.2	29.7-43.0	29.7±3.2	22.1-36.2	0.000
	Lee (2000)	29.6±5.2	20.2-42.7	35.6±4.1	29.4-42.7	26.9±2.8	20.2-33.5	0.000
Fat Mass (kg)	DXA	13.6±4.3	4.7-27.6	12.5±5.5	6.0-27.6	14.1±3.6	4.7-22.2	0.153
	Fractionation (1980)	7.8±2.3	3.7-16.4	7.3±3.0	4.1-16.4	8.1±2.0	3.7-13.1	0.076
Fat Mass (%)	DXA	19.0±5.3	8.7-30.9	15.2±5.7	9.3-30.9	20.7±4.1	8.7-30.1	0.000
	Fractionation (1980)	11.5±3.0	6.1-18.5	9.0±3.0	6.1-18.5	12.3±2.4	7.2-18.4	0.000

	Withers (1987)	12.5±4.4	5.5-27.1	10.3±5.1	5.5-27.1	13.5±3.8	5.9-24.7	0.007
	Reilly (2009)	12.6±2.9	7.8-20.9	11.0±3.2	7.8-20.9	13.4±2.4	8.4-19.2	0.001
Indexes (kg/m²)	Body Mass	23.3±4.4	17.9-30.4	24.6±2.9	20.2-30.4	22.7±2.1	17.9-28.8	0.030
	Fat Mass	4.5±1.4	1.7-8.7	3.9±1.7	2.0-8.7	4.8±1.2	1.7-7.6	0.009
	Fat Free Mass	19.0±2.2	15.6-27.3	21.0±2.4	17.9-27.3	18.0±1.4	15.6-21.5	0.000

Data are Mean (μ) ± Standard Deviation (SD); Minimum (Min); Maximum (Max); DXA=Dual Energy X-Ray Absorptiometry; DXA Fat Free Mass=DXA lean body mass and bone mineral content; Fractionated Fat Free Mass=fractionated muscle mass, fractionated residual mass and fractionated bone mass; Fractionated Lean Body Mass=fractionated muscle mass and fractionated residual mass; Body Mass Index=body mass (kg)/height (m^2); Fat Mass Index=DXA fat mass (kg)/height (m^2); Fat Free Mass Index=DXA Fat Free Mass (kg)/ height (m^2).

Table 4. Least square regression analysis of anthropometric models in elite Canadian athletes

Group	Equation	μ±SD (kg)	Intercept	Slope	SEE	r	M 95% PI*
All	**DXA FFM**	**57.9±9.9**					
N = 64	Fract. FFM	60.4±9.0	0.77 (-4.31-4.46)	0.96 (0.89 - 1.03)	2.56	0.96 (0.82 - 1.02)	1.74 (3.49)
	Withers, FFM	61.9±8.7	-5.01 (-8.09-1.93)	1.02 (0.97 - 1.07)	1.70	0.98 (0.90 - 1.03)	1.15 (2.29)
	Reilly, FFM	61.9±8.6	-4.49 (-8.64-0.33)	1.00 (0.94 - 1.07)	2.27	0.97 (0.86 - 1.03)	1.54 (3.08)
	DXA LBM	**54.8±8.6**					
	Fract. LBM	49.6±7.2	-1.50 (-6.11-3.11)	1.14 (1.02 - 1.23)	2.64	0.95 (0.81 - 1.02)	1.80 (3.60)
	DXA SMM	**29.6±5.6**					
	Fract. SMM	32.1±5.1	-3.99 (-6.54-(-1.44)	1.05 (0.97 - 1.13)	1.58	0.96 (0.89 - 1.03)	1.57 (3.13)
	Lee, SMM	29.6±5.2	-0.54 (-2.93-1.86)	1.01 (0.94 - 1.10)	1.64	0.96 (0.88 - 1.03)	1.65 (3.30)
Females	**DXA FFM**	**53.4±5.2**					
N = 44	Fract. FFM	55.9±5.6	3.71 (-1.91 - 9.31)	0.89 (0.79 - 0.99)	1.80	0.94 (0.84 - 1.05)	1.60 (3.19)
	Withers, FFM	57.9±5.5	0.52 (-4.33-5.38)	0.91 (0.83 - 1.00)	1.50	0.96 (0.87 - 1.05)	1.05 (2.11)
	Reilly, FFM	58.0±5.8	3.54 (-1.80 - 8.87)	0.86 (0.77 - 0.95)	1.72	0.95 (0.85 - 1.05)	1.42 (2.84)
	DXA LBM	**50.5±5.0**					

	Fract. LBM	46.1±4.6	3.76 (-1.68 - 9.20)	1.02 (0.90 - 1.13)	1.76	0.94 (0.83 - 1.05)	1.65 (3.30)
	DXA SMM	**26.9±3.3**					
	Fract. SMM	29.7±3.3	-0.87 (-4.54-2.77)	0.94 (0.82 - 1.06)	1.30	0.92 (0.75 - 0.97)	1.07 (2.15)
	Lee, SMM	26.9±2.8	-0.88 (-5.36-3.61)	1.03 (0.87 - 1.20)	1.53	0.89 (0.75 - 1.03)	1.27 (2.54)
Males	**DXA FFM**	**66.7±7.5**					
N = 20	Fract. FFM	70.9±7.0	1.12 (-17.66 - 19.89)	0.95 (0.68 - 1.21)	3.80	0.87 (0.63 - 1.11)	2.10 (4.21)
	Withers, FFM	70.9±7.5	-1.12 (-9.08-6.84)	0.97 (0.86 - 1.08)	1.74	0.97 (0.86 - 1.09)	1.37 (2.74)
	Reilly, FFM	70.5±7.6	1.77 (-9.94-13.47)	0.94 (0.77 - 1.10)	2.59	0.94 (0.78 - 1.10)	1.82 (3.64)
	DXA LBM	**64.3±7.3**					
	Fract. LBM	58.1±5.7	0.49 (-19.19-20.16)	1.11 (0.77 - 1.45)	3.95	0.85 (0.59 - 1.11)	2.16 (4.31)
	DXA SMM	**35.6±4.8**					
	Fract. SMM	38.0±4.3	-3.32 (-12.72-6.09)	1.02 (0.78 - 1.27)	2.17	0.90 (0.71 - 1.16)	1.38 (2.76)
	Lee, SMM	35.6±4.1	-3.60 (-11.75-4.56)	1.10 (0.87 - 1.33)	1.92	0.92 (0.73 - 1.11)	2.51 (5.02)

Data are Mean (μ) ± Standard Deviation (SD); Fract. = Fractionated; Range in parentheses = 95% interval; M95%PI = mean 95% prediction interval of the DXA-FFM vs Fractionated FFM; DXA-LBM vs Fractionated LBM; DXA SMM vs Fractionated SMM; DXA SMM vs Lee, SMM; r = correlation coefficient; SEE = standard error of the estimate. PI* ranges calculated by multiplying the mean 95% PI interval by 2 (ranges in parentheses).

Table 5. Multiple regression using Withers, Reilly & Lee specified measurement sites and multiple regression with forward selection to develop new 'Sesbreno' anthropometric fat free mass and muscle mass equation for elite athletes

Criterion	**Equation**	**Intercept**	**Tricep SF**	**Abd. SF**	**Thigh SF**	**Calf SF**	**Sum 7 SF**	**Fract. FFM**	**Fract. FM**			**R2**
DXA FFM	Sesbreno (2019)	3.397 (2.005)						0.975 (0.031)	-0.576 (0.120)			0.94
	Withers (1987)	63.390 (3.278)					-0.077 (0.043)					0.05
	Reilly (2009)	65.539 (2.816)	-0.530 (0.414)	0.373 (0.179)	-0.931 (0.251)	0.874 (0.442)						0.32
Criterion	**Equation**	**Intercept**	**Height**	**Age**	**Sex**	**Race**	**C.Arm Girth**	**C.Thi. Girth**	**C.Cal. Girth**	**Fract. SMM**	**Fract. FM**	**R2**
DXA SMM	Sesbreno (2019)	-2.485 (1.313)								1.058 (0.037)	-0.235 (0.081)	0.93
	Lee (2000)	-36.293 (5.384)	0.270 (3.200)	0.076 (0.043)	0.281 (0.600)	0.021 (0.371)	0.260 (0.002)	0.233 (0.001)	0.258 (0.002)			0.94

Sixty-four participants from this study were included; Standard error is shown in parentheses. Abd. = Abdominal, SF = Skinfold (mm), Fract. FFM = Fractionated fat free mass (kg), Fract. FM = Fractionated fat mass (kg), Fract. SMM = Fractionated skeletal muscle mass (kg), C.Arm girth = corrected arm girth (cm), C.Thi girth = corrected mid-thigh girth (cm) and C.Cal girth = corrected calf max girth (cm).