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Original Article

Dual-Energy X-Ray Absorptiometry Measured Regional Body Composition Least Significant Change: Effect of Region of Interest and Gender in Athletes

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Abstract

Dual-energy X-ray absorptiometry (DXA) is widely used to evaluate body composition in athletes. Knowledge of measurement precision is essential for monitoring body composition changes over time. This study begins characterizing DXA body composition precision in 60 (30 males and 30 females) Division 1 athletes focusing on gender, regional, and tissue type differences. Two total body scans with repositioning between were performed on the same day. Least significant change (LSC) for the root-mean-square deviation (LSC_{RMSD}) and the percent coefficient of variation ($LSC_{\%CV}$) for total, lean, and fat mass was calculated for 6 regions of interest. The effect of gender, region, tissue type, and mass on the standard deviation (SD) and percent coefficient of variation (%CV) between the 2 scans was evaluated using repeated measures regression analysis. Statistically significant effects of gender, region, tissue type, and mass on SD and %CV were noted. To generalize, a nonlinear positive relationship between LSC_{RMSD} and mass and a nonlinear negative relationship between $LSC_{\%CV}$ and mass were observed. In conclusion, DXA body composition LSC varies among genders, regions, tissues, and mass. As such, when evaluating serial body composition in athletes, especially if assessing regional change, knowledge of precision in individuals of similar body size and gender to the population of interest is needed.

Key Words: Body composition; DXA; precision; sports performance.

Introduction

Dual-energy X-ray absorptiometry (DXA) is increasingly being used to measure body composition in various settings *(1)*, including obesity/bariatric surgery *(2,3)*, lipodystrophy assessment in individuals with HIV *(4−7)*, sarcopenia *(8−11)*, and athletic training/performance *(12−16)*. This methodology is rapid, relatively inexpensive, and uses only a small amount of ionizing radiation. Importantly, it allows regional composition measurements, which have primarily received interest for assessing fat distribution (i.e., android/gynoid fat) *(17)* and appendicular lean mass as part of sarcopenia definition *(8,9,11)*. However, the ability to evaluate regional lean mass carries substantial potential for assessing athletes to evaluate training regimens and also rehabilitation after sports injuries. This ability to evaluate not only total fat and lean mass but also mass in specific regions such as the extremities is a distinct advantage of DXA compared with other measures of body composition, such as bioelectrical impedance or hydrodensitometry *(18,19)*.

In general, a high lean mass-to-fat mass ratio is beneficial for most athletes because high body fat mass leads to less efficient energy utilization *(20)*. However, too little fat mass might negatively impact health as seen in women with female athlete triad (disordered eating, amenorrhea, and low bone mineral density) *(21)*. Despite the potential advantages noted

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previously, only a limited number of studies have used DXA body composition in athletes. Some reports find a high correlation between DXA and other measures of body composition *(12,21−24)*. However, other studies comparing athletes with controls observe differences in body composition, for example, among different Cricketing skill groups and Rugby player positions *(14,16)*. Importantly, serial DXA scans may be used to assess body composition changes over time to monitor training regimens or during the course of a season *(13)*. One can speculate that such serial DXA body composition evaluation in athletes might be most beneficial as it can provide information about not only conditioning status, training regimens, or rehabilitation process but also negative developments that might impact the athletes' health, such as excessive loss of fat or lean mass.

In serial measurements, however, it is necessary to appreciate and account for method variability to determine if an intervention has altered fat and/or lean mass over time. The International Society for Clinical Densitometry (ISCD) recommends performance of a precision assessment to determine what constitutes a change in the measured parameters with 95% confidence interval *(25−27)*. Importantly, such a precision assessment should be performed "using patients representative of the clinic's patient population" *(26)*. Because diverse populations with markedly differing body composition may be evaluated depending on the clinical circumstance, it is necessary to understand if variations in body composition, body size, and fat/lean distribution affect reproducibility of these measurements. One obvious example of differences is gender, with males typically being larger with different fat/lean distribution compared with females *(28,29)*. Moreover, although the reproducibility of total body bone, fat, and lean mass has been reported and appears to be excellent in adults with and without disease *(6,30−32)*, there is, to our knowledge, only limited information available regarding the reproducibility of these measurements in athletes *(12)*. Furthermore, only very limited data exist regarding the reproducibility of regional measurements in this population. As elite athletes are very specialized and have widely differing body compositions, we hypothesized that the size and body composition of Division 1 college athletes might be variable enough to warrant separate precision assessments. The goal of this study was to do an initial evaluation of total and regional body composition in Division 1 athletes with focus on gender, tissue, and regional differences.

Methods

Participants

As recommended by the ISCD, precision assessments consisting of 2 total body DXA scans were performed in 60 student athletes (30 females and 30 males) from the University of Wisconsin selected based on the ability to fit within the densitometer scan field. Mean (± standard deviation [SD]) age was 20.6 (±1.3) yr (range, 18.3−23.4 yr) and 19.9 (±1.3) yr (range, 18.1−22.7 yr) for men and women, respectively. These athletes participated in various sports including hockey (17 women and 16 men), basketball (5 women and 4 men), golf (8 women), and wrestling (10 men). This study was determined to be exempt by the University of Wisconsin-Madison Institutional Review Board. All participants provided written consent before undergoing DXA assessment.

DXA Acquisition, Analysis, and Precision Assessment

A GE Healthcare (Madison, WI) Lunar iDXA densitometer was used for all examinations. ISCD-certified technologists performed all scan acquisition and analyses in routine clinical manner following research facility standard operating procedures. All scans were acquired using enCORE software versions 11.0−13.31; version 13.4 was used for analysis. One technologist analyzed all scans using the software autoanalysis feature followed by manual correction of analysis markers when necessary.

Precision assessment was performed in routine clinical manner following ISCD recommendations *(26)*; specifically, each athlete was scanned twice by the same technologist with repositioning between scans. Both scans were conducted at the same scanning session.

DXA Regional Analysis

Total body and regional analyses were performed in routine clinical manner. Six standard regions of interest (ROI) were used for this analysis (Fig. 1). These regions were defined as follows: Total body ROI consisting of the entire body including the head; trunk ROI defined at the upper boundary by the mandible line including the chest, abdomen, and pelvic triangle; the arm ROIs (right and left) were defined by a line bisecting the shoulder joint of the right and left arm; and the leg ROIs (right and left) were defined by a line bisecting the hip joint aligned with the iliac crest and pubis.

Statistical Analyses

The gender differences in age and body mass index (BMI) were evaluated using Student's *t*-test. The mean mass, variance and SD between the measurements, and percent coefficient of variation (%CV) were calculated for each subject based on the 2 scans, resulting in 18 observations of each parameter (mean, variance, SD, and %CV) that corresponds to the region (total, trunk, left arm, right arm, left leg, and right leg) and tissue type (total, fat, and lean) combinations. The mean square error (MSE) and least significant change (LSC) with 95% confidence interval based on both the MSE (least significant change for the root-mean-square deviation [LSC_{RMSD}]) and %CV (least significant change for the percent coefficient of variation [$LSC_{\%CV}$]) were calculated for each region and tissue type for males and females using the ISCD precision calculator available online (http://www.iscd.org/visitors/resources/calc.cfm). The LSC values are a multiple of either the RMSD or root-mean-square %CV; hence, inferences based on the SD or %CV are applicable to the LSC

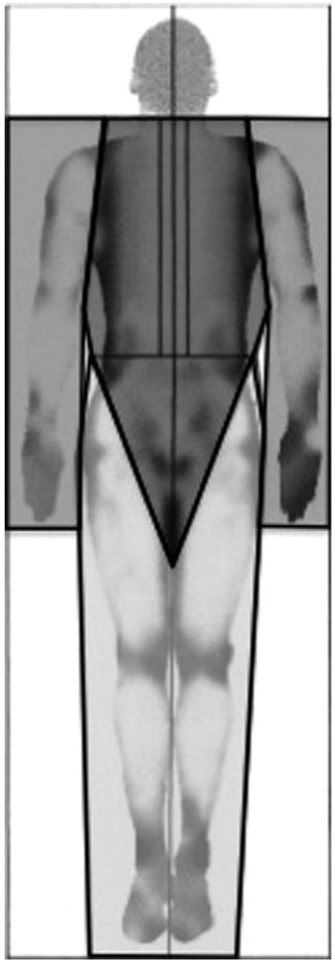

Fig. 1. Total body regions of interest (ROIs). This figure depicts the total body DXA ROIs reported in this analysis. The total body region includes the entire body. The trunk region includes the pelvic triangle to the inferior mandible (noted by dark gray). The arm ROI includes the area bisected at the shoulder joint (noted in medium gray). The leg region is bisected at the hip and excludes the pelvic triangle (noted in light gray).

values. Wilcoxon rank-sum test was used to evaluate gender differences in variance for total, fat, and lean mass for each region and tissue type. The graphical evaluation of the relationship between mean mass for each region/tissue combination with corresponding mean LSC_{RMSD} and mean $LSC_{\%CV}$ was assessed in JMP (version 10.0; SAS Institute, Cary, NC) using a best-fit model. Repeated measures models with unstructured covariance matrices and Kenward-Roger approximation *(33)* were used to assess the effect of gender, region, tissue type, and mass on the SD and %CV. All analyzes were done with SAS v9.3 (Cary, NC).

Results

Body Composition

The body composition results are given in Table 1. Males were larger than females ($p < 0.01$). Specifically, for men, the mean (±SD) BMI was 25.6 (±3.0) kg/m^2 (range, 21.3−35.7 kg/m^2), and for women, it was 23.3 (±2.3) kg/m^2 (range, 17.7−29.4 kg/m^2). The mean total mass for men was 85.2 kg (range, 62.7−123.7 kg), and for women, it was 65.5 kg (range, 52.0−77.1). There was little overlap in total mass between the men and women, in that the heaviest 24 individuals were male. Absolute and percent lean mass measurements were higher in men than in women ($p < 0.001$) at all ROIs. Fat mass measurements were higher in women ($p < 0.05$) at all ROIs.

Table 1
Demographics and Body Composition in Athletes by Gender

	Male		Female	
Characteristics	Mean	SD	Mean	SD
Age, yr	20.6	1.3	19.9	1.3
Height, cm	180.0	7.1	166.7*	5.3
Weight, kg	83.4	11.9	65.0*	6.3
BMI, kg/m^2	25.6	3.0	23.3*	2.3
Total body ROI (g)				
Total mass	85,200	12,560	65,535	6506
Lean mass	68,077	8595	45,871	4724
Fat mass	13,340	6000	16,932	3293
Trunk ROI (g)				
Total mass	40,226	5684	30,873	3292
Lean mass	32,676	3873	22,628	2366
Fat mass	6298	3300	7385	1912
Right arm ROI (g)				
Total mass	5357	812	3527	424
Lean mass	4431	676	2426	329
Fat mass	645	247	922	191
Left arm ROI (g)				
Total mass	5262	839	3454	388
Lean mass	4280	692	2325	307
Fat mass	707	266	955	189
Right leg ROI (g)				
Total mass	14,710	2691	11,703	1349
Lean mass	11,657	1730	7795	922
Fat mass	2348	1172	3402	660
Left leg ROI (g)				
Total mass	14,656	2582	11,732	1473
Lean mass	11,516	1744	7734	1032
Fat mass	2435	1070	3495	653

Note: Lean mass was higher in men ($p < 0.001$), and fat mass was higher ($p < 0.05$) in women at all sites.

Abbr: BMI, body mass index; ROI, region of interest SD, standard deviation.

*$p < 0.01$ using *t*-test for between-genders comparison.

Precision

The LSC_{RMSD} and $LSC_{\%CV}$ values varied between the different regions, tissues, and genders (Table 2). The Wilcoxon rank-sum tests indicated that variance is smaller for females

Table 2
Precision and LSC by ROI and Gender

	Precision						LSC (95% confidence)			
Gender	Male			Female			Male		Female	
Site	RMS SD	%CV	MSE	RMS SD	%CV	MSE	LSC_{RMSD}	$LSC_{\%CV}$	LSC_{RMSD}	$LSC_{\%CV}$
Total body ROI										
Total mass	63	0.07	3958	46	0.07	2121	174	0.2	128	0.2
Lean mass	208	0.30	43,155	138	0.30	18,938*	575	0.8	381	0.8
Fat mass	168	1.46	28,186	114	0.64	13,000*	465	4.1	316	1.8
Trunk ROI										
Total mass	184	0.46	33,716	142	0.47	20,240	509	1.3	394	1.3
Lean mass	265	0.80	70,173	170	0.77	28,978*	734	2.2	472	2.1
Fat mass	149	2.79	22,217	110	1.46	12,086	413	7.7	305	4.0
Right arm ROI										
Total mass	45	0.86	2050	47	1.35	2191	125	2.4	130	3.7
Lean mass	55	1.34	3044	59	2.54	3508	153	3.7	164	7.0
Fat mass	37	7.09	1361	33	3.85	1105	102	19.6	92	10.7
Left arm ROI										
Total mass	69	1.36	4758	45	1.27	2053	191	3.8	126	3.5
Lean mass	78	1.85	6047	55	2.43	2983	215	5.1	151	6.7
Fat mass	48	8.00	2313	35	4.34	1195	133	22.2	96	12.0
Right leg ROI										
Total mass	137	0.91	18,796	170	1.34	28,768	380	2.5	470	3.7
Lean mass	131	1.08	17,181	140	1.68	19,723	363	3.0	389	4.7
Fat mass	47	2.18	2200	56	1.54	3089	130	6.0	154	4.3
Left leg ROI										
Total mass	184	1.25	33,778	173	1.39	30,002	509	3.5	480	3.8
Lean mass	166	1.44	27,612	112	1.41	12,533	460	4.0	310	3.9
Fat mass	71	3.33	4984	78	2.08	6079	196	9.2	216	5.8

Note: ROI masses, RMS SD, and LSC_{RMSD} values in grams.

Abbr: %CV, percent coefficient of variation; LSC, least significant change; $LSC_{\%CV}$, least significant change for the root-mean-square percent coefficient of variation; LSC_{RMSD}, least significant change for the root-mean-square deviation; MSE, mean square error; RMS SD, root-mean-square error standard deviation; ROI, region of interest.

*$p < 0.05$ using Wilcoxon rank-sum test to compare variances between genders.

than that for males in the fat and lean tissues of the total body ($p < 0.01$) and in the lean tissue of the trunk ($p = 0.03$).

The graphical evaluation of the relationships between mean ROI/tissue mass and LSC_{RMSD} and between mean ROI/tissue mass and $LSC_{\%CV}$ showed that LSC_{RMSD} increases ($R^2 = 0.47$) and %CV decreases ($R^2 = 0.81$) in a nonlinear fashion as the amount of regional mass increases (Fig. 2).

Due to nonlinearity of the relationships between the mass and measures of precision, the dependent variables (SD and %CV) were transformed using natural logarithm for estimating the effects of gender, region, and tissue type on SD and %CV in repeated measures regression analyses (Table 3). Subsequently, the estimated effects of the explanatory variables were obtained using reversed transformation of the model parameters. As noted in Table 3, the SD and %CV for female athletes were 81% and 97% compared with males, respectively, with the effect being statistically significant ($p = 0.026$) for SD. Variability also differed based on ROI. Specifically, variability based on SD for the left arm ROI, right arm ROI, and right leg ROI was less than that for the total body ROI (41%, 45%, and 95%, respectively) and greater than that for the total body ROI in left leg ROI and trunk ROI (110% and 161%). The effect of ROI was statistically significant ($p < 0.001$) for both arms and the trunk. Similar analysis for variability based on %CV revealed that % CV for all regions was greater ($p < 0.001$) compared with that for the total body: 343% (trunk), 519% (right leg ROI), 606% (left leg ROI), 717% (left arm ROI), and 791% (right arm ROI). Additionally, variability of fat and lean mass measurements differed from that of total mass. Specifically, the SD for fat tissue was 70% of that for total ($p < 0.001$), and the SD for lean tissue was 117% of that for total ($p = 0.02$). However, in similar analysis for %CV, both lean and fat tissue %CV values

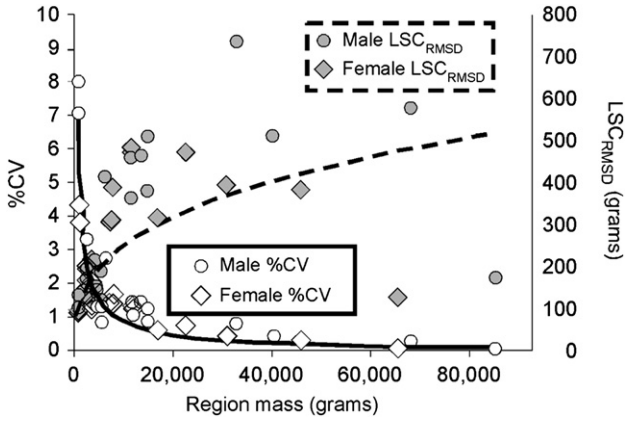

Fig. 2. Relationship of LSC_{RMSD} and %CV with mass. Graphically, there is a strong positive nonlinear relationship ($r^2 = 0.47$) between LSC_{RMSD} and mass and a strong negative nonlinear relationship ($r^2 = 0.81$) between %CV and mass. %CV, percent coefficient of variation; LSC_{RMSD}, least significant change for the root-mean-square deviation.

were greater ($p < 0.01$) compared with %CV for total tissue: 162% for lean and 332% for fat tissue.

To account for different tissue composition and variability in mass between regions, the same models were used with log mean mass instead of region as an explanatory variable (Table 4). The effect of gender was statistically significant in both models ($p = 0.024$) with both SD and %CV for females being 80% of that for males. Variability of lean mass was 124% of that for total mass ($p = 0.003$). The natural log of SD increases by 0.22 for every unit increase in the log of the mean mass ($p < 0.001$), and when converted to the natural scale, the SD is the mean mass raised to the 0.22 power. This suggests that although the SD increases as the mean mass increases, the rate of increase is greater for smaller masses. Conversely, the log of %CV decreases by 0.78 for every unit increase in the log of the mean mass ($p < 0.001$). Converted to the natural scale, the estimated %CV is the mean mass raised to the −0.78 power. This suggests that although the %CV decreases as the mean mass increases, the rate of decrease is greater for the smaller values of the mass.

Discussion

In male and female Division 1 athletes, a group of lean and fit individuals, precision of DXA body composition is excellent for total body and lean mass in all regions assessed in this study. As a clinical generalization, measurement variability was greater in men and differed between lean, fat, and total mass. Moreover, variability generally increases as mass increases, in that measurement sites with larger mass also had higher LSC_{RMSD} and lower $LSC_{\%CV}$ values in a nonlinear relationship.

Studies evaluating DXA body composition precision are currently quite limited. DXA body composition precision has been reported in nonobese adults *(34)*, young individuals (not athletes) *(17)*, obese populations *(31)*, individuals from the Diabetes Heart Study *(30)*, and individuals with HIV

Table 3
Effect of Gender, ROI, and Tissue Type on SD and %CV

	SD		%CV	
Effects	Multiplying factor (95% CI)	*p* Value	Multiplying factor (95% CI)	*p* Value
Gender				
Female	0.81 (0.67−0.97)	0.026	0.97 (0.80−1.17)	0.715
Male[a]	Reference	—	Reference	—
ROI				
Right arm	0.45 (0.34−0.60)	<0.001	7.91 (5.94−10.53)	<0.001
Left arm	0.41 (0.31−0.53)	<0.001	7.17 (5.51−9.33)	<0.001
Right leg	0.95 (0.71−1.28)	0.751	5.19 (3.90−6.90)	<0.001
Left leg	1.10 (0.85−1.43)	0.446	6.06 (4.69−7.85)	<0.001
Trunk	1.61 (1.35−1.92)	<0.001	3.43 (2.86−4.11)	<0.001
Total[a]	Reference	—	Reference	—
Tissue type				
Fat mass	0.70 (0.60−0.80)	<0.001	3.32 (2.72−4.04)	<0.001
Lean mass	1.17 (1.03−1.34)	0.020	1.62 (1.42−1.84)	<0.001
Total mass[a]	Reference	—	Reference	—

Note: The multiplying factor and the corresponding 95% CI were estimated from the repeated measures regression models on transformed values (natural logarithm) with SD or % CV as dependent variables and gender, ROI, and tissue type as explanatory variables.

Abbr: CI, confidence interval; %CV, percent coefficient of variation; ROI, region of interest; SD, standard deviation.

[a]Reference category.

Table 4
Effect of Gender, Tissue Type, and Mean Mass on SD and %CV

	SD		%CV	
Effects	Multiplying factor (95% CI)	*p* Value	Multiplying factor (95% CI)	*p* Value
Gender				
Female	0.80 (0.66−0.97)	0.024	0.80 (0.66−0.97)	0.024
Male[a]	Reference	—	Reference	—
Tissue mass				
Fat mass	1.07 (0.87−1.33)	0.510	1.07 (0.87−1.33)	0.510
Lean mass	1.24 (1.08−1.43)	0.003	1.24 (1.08−1.43)	0.003
Total mass[a]	Reference	—	Reference	—
Mean mass	[b]	<0.001	[c]	<0.001

Note: The multiplying factor and the corresponding 95% CI were estimated from the repeated measures regression models on transformed values (natural logarithm) with SD or %CV as dependent variables and gender, tissue type, and mean mass as explanatory variables.

Abbr: CI, confidence interval; %CV, percent coefficient of variation; SD, standard deviation.

[a]Reference category.

[b]Mean mass raised to the power (95% CI) of 0.22 (0.13−0.30).

[c]Mean mass raised to the power (95% CI) of −0.78 (−0.87 to −0.70).

(6). As expected, in these reports, the %CV varied among the population studied, the type of densitometer used, between fat and lean mass, and region studied. Percent CV values were generally below 4% *(6,17,30,31,34)*, similar to that observed for most of the ROIs in this study. Consistent with our findings, most prior studies report %CV values to be higher for fat mass compared with those for lean and total mass. In obese individuals, regional values were also comparable with those found in our athletes, whereas other studies reported lower %CV studies for fat mass *(31)*. Studies that examined separate regions also noted that precision was poorer when smaller regions have been evaluated, such as a single extremity compared with larger region like the total body *(6,31,34)*.

Although DXA body composition has been compared with other methods to assess body composition in athletes *(21−24)*, only limited data exist on the reproducibility of serial measurements in athletic populations *(12,24,35,36)*. One study *(12)* reported the %CV for fat mass to be 2.9%, but no data for regions or lean mass were reported. A more recent study that included 31 athletes reported whole-body lean and fat mass %CV values of 1.1% and 3.7%, respectively *(37)*. Additionally, a recent report of physically active young adults found the short-term %CV to be lowest for total mass (0.1%) with total lean and fat mass values of ∼0.5% and ∼1.5% *(36)*. These authors appropriately emphasize the potential impact of exercise sessions on body composition; however, such effects do not impact the data reported here, given that these scans were performed at the same session. However, fluid and food intake and loss should be considered when monitoring body composition change over time in athletic populations *(36)*. To this end, it has been suggested that athletic subjects be fasting and rested before DXA measurement *(35)*. Further study of training and food effects on body composition measurement, ideally leading to standardization of measurement approaches, is needed.

DXA body composition assessment promises to be a valuable tool for athletes—it is rapid, relatively uncomplicated, and has very low radiation exposure. Various sports performance−related indications could be proposed including comparing body composition among different sports, different positions within team sports, or screening promising young athletes for lean, fat, and bone mass. However, in our opinion, most appealing might be the use of DXA body composition for serial measurement to monitor body composition changes over time to monitor training programs and/or injury and subsequent rehabilitation. To be able to assess whether a measured body composition change is larger than the variability of the assessment itself, a precision analysis must be performed. This can be easily performed using a relatively small number of individuals with LSC_{RMSD} and $LSC_{\%CV}$ being determined using the existing calculators available online *(25−27)*.

Limitations of this study include the small sample size of 60 participants, use of only a single manufacturer's densitometer, and study of only young Division 1 athletes from a limited number of sports. As such, generalization to one particular sport or another densitometer is limited. In addition, whether similar results are obtained in nonathletic populations remains to be determined. Importantly, whether the observed differences in LSC_{RMSD} and $LSC_{\%CV}$ are solely related to ROI mass, or whether other factors also play a role cannot be determined from this work because of the relatively small number and heterogeneous sample of these athletes. Additional studies are necessary to further define whether there is a gender and/or tissue type effect on precision or whether the differences observed in this study are simply because of larger body size of the males in this cohort.

In conclusion, in this group of Division 1 athletes, fat and lean mass SD and %CV and the corresponding LSC_{RMSD} and $LSC_{\%CV}$ values differed by gender, ROI, tissue type, and mass. Based on analyses of the SD, males have greater variability than females and lean mass has greater variability than fat and total mass, perhaps because of their larger body size. Descriptively, a strong nonlinear positive relationship between LSC_{RMSD} and mass and a negative relationship between $LSC_{\%CV}$ and mass were observed. Thus, to over simplify, variability increases as mass increases and the rate of increase is greater for smaller masses. When using serial total body DXA to evaluate regional fat and lean mass changes in athletes, determination of the LSC values for the body ROIs is essential. Moreover, performance of precision assessment in individuals similar in body size and composition is necessary.

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