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Accuracy and Reliability of Assessing Lateral Compartmental Leg Composition Using DXA

Christiana J. Raymond¹, Tyler A. Bosch², Foster K. Bush¹, Lisa S. Chow³, and Donald R. Dengel^{1,4}

¹Laboratory of Integrative Human Physiology, School of Kinesiology, University of Minnesota, Minneapolis, MN

²College of Education and Human Development, University of Minnesota, Minneapolis, MN

³Department of Medicine, University of Minnesota Medical School, University of Minnesota, Minneapolis, MN

⁴Department of Pediatrics, University of Minnesota Medical School, Minneapolis, MN

Abstract

Purpose—Investigate the accuracy and reliability of a novel dual X-ray absorptiometry (DXA) scanning method in the frontal plane for total, fat, and lean mass quantification of the anterior and posterior upper leg compartments.

Methods—Twenty-one (11 female; $\bar{X}_{age}=20.3\pm1.3$ yrs) college athletes were assessed for total and regional body composition using DXA. Segmentation of anterior/posterior thigh compartments was measured with participants lying on their right and left sides and the scanned leg elevated with two foam pads. Custom regions of interest (ROIs) were created manually with *encore*^{TM} software for each scan using bony landmarks to quantify lean, fat, and total masses. Paired t-tests assessed this novel positioning method's accuracy against standard positioning. Intra-class correlations (ICCs) and coefficients of variation (CV) examined inter- and intra-rater reliability for lateral scan measures of total, fat, and lean masses from manually created ROIs.

Results—All mean differences ($\pm$ SD) between frontal and lateral DXA scans of right (R) and left (L) leg total mass (R: 8.42 ± 195.57 g; L: 19.47 ± 131.80 g), fat mass (R: 61.26 ± 215.66 g; L: -5.89 ± 239.97 g), and lean mass (R: -103.00 ± 302.54 g; L: -27.58 ± 288.14 g) were non-significant (p -value range: 0.15 to 0.91). ICCs were high for all composition measures between- and within-raters, ranging from 0.983 to 0.999 and 0.954 to 0.999, respectively, with low variation across measures (all CVs: <5%).

Conclusion—The results of this study suggest that DXA measures using lateral subject positioning and custom ROIs to assess upper leg total, fat, and lean masses are accurate and reliable compared with total-body frontal subject positioning. Future studies are needed to

Corresponding Author: Christiana J. Raymond, Address: School of Kinesiology, University of Minnesota, 1900 University Avenue SE, Minneapolis, MN 55455, Phone: 614-595-5997, Fax: 612-625-8867, raymo191@umn.edu.

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determine the clinical usefulness of lateral view measures regarding prevention or rehabilitation of sports- or age-related injury.

Keywords

Dual X-ray Absorptiometry; Segmentation; Region of Interest; Lean Mass; Fat Mass

Introduction

Body composition assessment has been used clinically to examine bone disease (e.g., osteoporosis), skeletal muscle loss (e.g., sarcopenia), visceral adiposity, and the effectiveness of physical rehabilitation efforts, among other purposes (3,13,16,22). Multiple body composition methods have been developed, including anthropometry, hydrodensitometry, bioelectrical impedance analysis (BIA), computed tomography (CT), magnetic resonance imaging (MRI), and dual X-ray absorptiometry (DXA). DXA is currently considered the “gold standard” for the quantitative assessment of total and regional body composition and bone mineral density (BMD) in both adults and children (11,19,20). Current literature reports valid and reliable comparisons of total and regional body composition values using DXA in the standard frontal plane view in various populations (3,4,6,8,10,14,15) against the criterion 4-component model (bone mineral, fat mass, lean mass, total body water) and other body composition assessment methods (5,7,13,22,23).

Recent DXA software developments allow for both automatically- and manually-generated regions of interest (ROIs) to quantify regional (e.g., arms, legs, trunk) body composition measures including contralateral (right vs. left) body comparisons and visceral adiposity measurements (10,13,14,16). Recent studies (5,13) using DXA have assessed regional quantification of bone mass, fat mass (FM), and lean mass (LM) in the upper (thigh) and lower (shank) legs in the frontal view, but DXA has not been used to measure specific ipsilateral (same leg) compartments (ex. anterior vs. posterior) within these respective regions. Notably, anterior and posterior compartments in the upper leg refer to pre-femoral and post-femoral soft tissue regions, respectively, as seen in the lateral view. Lateral subject positioning using DXA would provide a more in-depth body composition analysis—in addition to the standard total-body frontal scanning method—regarding ipsilateral symmetry, injury cause or prevention (via identifying opposing compartmental composition imbalances), athletic performance, and disease and aging processes, among others.

To the best of our knowledge, no studies have examined segmented measures of FM and LM in the lateral view using DXA technology. Therefore, in the present study we sought to: (1) Examine the accuracy of measures gathered using this novel “segmented lateral” scanning method compared with the same measures obtained using the total-body frontal DXA scanning method; (2) Quantify contralateral and ipsilateral tissue composition; and (3) Demonstrate the inter- and intra-rater reliability of using this novel method to assess compartmental (i.e., anterior/posterior) composition. We hypothesized that FM and LM measured by DXA in the traditional frontal position and novel lateral position would not significantly differ within individuals. If we observed no difference between the two

scanning methods, we planned to measure the inter- and intra-rater reliability of this segmented lateral scanning method using custom ROIs.

Methods

Study Participants

Twenty-one (10 male/11 female) participants aged 18-23 years (mean age 20.3 ± 1.3 years) were recruited from the University of Minnesota-Twin Cities campus. Participants were healthy and had a body mass index (BMI) $>18 \text{ kg/m}^2$. All participants wore minimal, light clothing free of metallic material. The study protocol was approved by the University of Minnesota Institutional Review Board and written informed consent was obtained from all participants.

Scan Procedures

All testing was performed at the Clinical and Translational Science Institute located within the Delaware Clinical Research Unit on the University of Minnesota campus between 8:00 am and 12:00 pm. Each participant's height and weight were measured using an electronic scale and wall-mounted stadiometer. BMI was calculated as the body weight in kilograms divided by height in meters squared. Study participant characteristics are presented in Table 1. All female participants were screened for a negative pregnancy test prior to undergoing DXA scans. Following height and weight measurements, total body composition was measured using standard procedures (9) in the supine position (Figure 1a) on a GE Lunar iDXA system (iDXA, General Electric Medical Systems, Madison, WI, USA) and scans were analyzed using encore™ software (platform version 16.0, General Electric Medical Systems, Madison, WI, USA). Following the full-body scan, participants underwent two DXA leg scans (right and left), using the full-body scan mode, to quantify FM and LM in the lateral view. The leg scans were completed after the scan had reached the shoulder, thereby excluding the head. Participants were repositioned for these segmented lateral scans by lying on their side (i.e., right side to scan the left leg, left side to scan the right leg) with their feet at the start of the scanning area (Figure 1b). The scanned leg was kept straight along the centerline of the DXA table while the other leg was bent and moved out of the scanning field. The scanned leg was elevated using foam pads at the ankle and a quarter length foam roller was used at the widest portion of the upper leg to keep the leg straight, maintain the shape of the muscle, and to ensure participant comfort. The pad used to support the thigh was scanned prior to the study by DXA to ensure it would not be recognized by DXA and influence the analyses. To create reliable landmarks, prior to scanning each leg, metallic markers were placed on each participant's lateral epicondyle and greater trochanter to identify ROIs for analyses.

Segmentation Quantification

Upon scan completion, a two-dimensional image was automatically produced for post-scan analysis. To examine the accuracy of using this segmented lateral scanning method as compared to the total-body frontal scanning method, custom ROIs of equal area were created on the frontal and lateral scans. The proximal border of each custom ROI was placed 60% of the length from the lateral epicondyle to the greater trochanter, and the distal border

was placed 60% of the length from the lateral epicondyle to the lateral malleolus (Figure 1a-b). Lateral and medial borders of the ROIs were placed outside the leg circumference, ensuring inclusion of the entire leg.

To examine the reliability of using the segmented lateral scanning method to assess compartmental composition, ROI boxes were manually created, each encompassing the respective anterior and posterior upper leg compartments. The anterior ROI borders were placed at the lateral epicondyle (distal), 80% of the length between the lateral epicondyle and greater trochanter (proximal), down the shaft of the femur (medial), and outside of the leg area (lateral). The posterior ROI borders were placed similarly, thereby mirroring the borders of the anterior ROI box (Figure 2). The proximal border was placed at 80% to ensure there was no tissue overlap with any other portion of the body (e.g., contralateral leg) while participants were lying on their side. To assess the reliability of using this segmented lateral scanning method, three investigators analyzed each participant's scans twice to facilitate evaluation of inter- and intra-rater reliability of total mass, FM, and LM.

Statistical Analyses

To examine the accuracy of this segmented lateral scanning method, paired t-tests were used to compare the composition from the lateral DXA scan to the standard total-body frontal DXA scan. Intra-class correlation coefficients (ICC) and coefficients of variation (CV) assessed the inter- and intra-rater reliability of the segmented lateral scan measures. All data were analyzed using statistical analysis software (SPSS Version 23.0; Chicago, IL), with α set at 0.05 for paired t-tests. The strength of reliability for ICCs was classified in accordance with Hopkins (15), with CVs below 5% considered highly reliable.

Results

Descriptive participant characteristics and baseline measurements are summarized in Table 1. Right and left leg measures of total tissue mass, FM, and LM between the total frontal and segmented lateral DXA scans—used to assess the accuracy of this lateral scanning method—are presented in Table 2. Notably, comparisons between the frontal and lateral view scans were all non-significant ($p > 0.05$; p -value range: 0.15 to 0.91). The mean difference $\pm$ SD between the two scan views of the right leg total, fat, and lean mass measures averaged over all participants were 8.42 ± 195.57 g, 61.26 ± 215.66 g, and -103.00 ± 302.54 g, respectively, and of the left leg total, fat, and lean mass measures were 19.47 ± 131.80 g, -5.89 ± 239.97 g, and -27.58 ± 288.14 g, respectively. Gender differences were examined by comparing mean differences of each mass measure in the right and left legs of males and females. No significant differences were found except for left leg FM (males: 118.20 g; females: -118.89 g).

Inter-rater Reliability

Quantified measures of total tissue mass, FM, and LM in the anterior/posterior compartments—used to assess reliability—are shown in Table 3. Segmented lateral compartmental analysis resulted in high inter-rater reliability for left and right leg measures of LM, FM, and total mass in the anterior and posterior compartments (Table 4). Inter-rater

CVs also demonstrated high reliability and precision for segmented lateral compartmental LM, FM, and total mass in the anterior and posterior compartments (Table 4). Segmented anterior and posterior leg measurements resulted in greater reliability and smaller variation than did segmented total (i.e., sum of anterior and posterior compartments) upper leg measurements across LM, FM, and total tissue mass. All inter-rater CVs for segmented total upper leg composition were 4.80% and for compartmental (i.e., anterior/posterior) composition were 3.55% (Table 4).

Intra-rater Reliability

Segmented lateral compartmental analysis resulted in strong intra-rater reliability for left and right leg measures of LM, FM, and total mass in the anterior and posterior compartments (Table 4). Intra-rater CVs also demonstrated high reliability and precision for LM, FM, and total mass in the anterior and posterior compartments (Table 4). Segmented total (i.e., sum of anterior and posterior compartments) upper leg measurements resulted in slightly lower reliability, on average, and larger CVs than those obtained for compartmental (i.e., anterior/posterior) measurements across LM, FM, and total mass. All intra-rater CVs for segmented total upper leg composition were 3.85% and for compartmental composition were 2.69% (Table 4).

Discussion

This is the first study to assess lateral subject positioning using DXA to analyze ipsilateral upper leg compartmental (i.e., anterior/posterior) composition. The current study demonstrates that the segmented lateral DXA scanning method developed by our research group is both accurate and reliable in assessing LM, FM, and total tissue mass compared to traditional scanning methods. This study observed no significant differences between the total-body frontal and segmented lateral DXA scan body composition measures in either leg of each participant. Inter- and intra-rater reliability was high for the quantification and assessment of segmented lateral upper leg compartment-specific LM, FM, and total tissue mass.

To understand the context of our findings, current literature only reports the high reliability of contralateral regional comparisons of the upper leg (thigh) and lower leg (calf muscles) in the traditional total-body frontal view using manually-generated ROIs and supine and prone subject positioning (5,13,18,23). As such, current literature does not report the accuracy nor the reliability of a lateral view DXA scan—a scanning method that would provide a more in-depth body composition analysis of ipsilateral symmetry and regional differences within a leg in athletic and clinical populations. The findings of this study therefore add to the current body of literature by providing initial accuracy and reliability support for utilizing lateral subject positioning as an additional method to assess body composition, including LM, FM, and total tissue mass, using DXA—not only for contralateral comparisons, as previous research (5,13,23) has examined, but also for ipsilateral compartmental (anterior vs. posterior) comparisons. While the preceding measurements may be possible using CT and MRI, the limitations associated with these two methods (i.e., cost, feasibility, accessibility, CT's radiation) make their use unlikely for assessing compartmental composition (1). In

comparison, DXA's increased feasibility and accessibility, lower cost, quick scan time, and minimal radiation make DXA a practical method to assess compartmental body composition.

Among athletes, current literature notes the utilization of DXA as a practical method to assess an athlete's body composition in the total-body frontal plane as it relates to performance and nutritional intervention (1). Nana and colleagues (21) note the use of this assessment to describe athletes' physical characteristics across sports or within the same sport (26,27), to examine an athlete's suitability for a weight class in a weight division sport (e.g., wrestling) (6), and to examine athletes' contralateral leg asymmetries—in the standard total-body frontal plane—for FM and LM measures (17). Therefore, a lateral scan analysis would not only provide information pertaining to athletes' physical characteristics and contralateral symmetry but also ipsilateral symmetry in opposing upper leg compartments. Further, examination of opposing ipsilateral, compartmental differences in the lower limbs may be more beneficial in assessing injury risk, causes of injury, and the rehabilitation process, as changes in body composition affect elite athletes' competitive performance (24). In fact, segmented lateral DXA scans would allow for longitudinal tracking of compositional changes (e.g., baseline/pre-injury, post-injury, before returning to play, etc., or over the course of multiple seasons) in opposing ipsilateral body compartments of athletes, as previous studies have made this assessment using the total-body frontal scanning method (2,25).

Clinically, precise and accurate body composition measurement is important in assessing certain medical conditions (e.g., sarcopenia), the aging process, and evaluating interventions (12). Additionally, segmented DXA body composition assessment methods may be useful in populations where standard DXA positioning remains a significant challenge (e.g., musculoskeletal disorders). This segmented lateral scanning method could be used to assess and longitudinally monitor body composition changes in elderly, diseased, and disabled populations affected by muscle wasting; this, in addition to monitoring LM improvements (and prevention of LM loss) over time in response to individualized therapeutic interventions (e.g., pre-therapy, midpoint, post-therapy). Therefore, the ability of this novel segmented lateral scanning method to evaluate opposing ipsilateral and contralateral regions of the body would provide greater insight into the injury, aging, and disease processes affecting LM and FM measures.

Major strengths of the current study include the study population's wide body composition variability (BMI range: 19.0-32.0 kg/m²) and the type of statistical analyses performed (paired t-tests and ICCs). The former allowed for reliability assessment across a broad BMI value range. A study population with a narrower BMI range may have resulted in lower variation in the standard deviation of the mean differences (i.e., greater accuracy) and smaller CV values (i.e., greater reliability)—biased results which, while desired, limit generalizability. Second, the within-subject statistical analyses chosen—for both accuracy and reliability examinations—controlled for differences between subjects.

Limitations of the current pilot study include its small sample size, potential systematic measurement errors in the manual generation of ROIs, and the limited custom ROI box size

due to the ankle foam pad. Specifically, the small sample size may have contributed to higher variation in the standard deviation of the mean differences comparing the two scanning methods and between- and within-raters reflected in higher CVs. Yet, despite its small sample size, this study provides initial evidence for this segmented lateral scanning method's accuracy and reliability. Second, although specific instructions detailed the manual production of ROI borders, slight differences in ROI box measurements may have occurred between the frontal and lateral scans and for compartmental tissue quantification between- and within-raters. Third, the ankle foam pad limited the custom ROI box size in comparing the two scanning methods, as frontal and lateral scan ROI borders were drawn to avoid pad inclusion. Further, the post-scan analysis of this segmented lateral scanning method may not be capable of fully separating muscle compartments—a limitation of the DXA scanner. Despite these limitations, no significant differences in body composition measures were observed between frontal and lateral scanning methods, and ICCs and CVs were reliable between- and within-raters. A larger sample size and greater precision of custom ROI borders may demonstrate higher reliability.

In conclusion, we made the novel observation that lateral subject positioning using DXA is an accurate and reliable method to assess compartmental composition, allowing for the assessment of LM, FM, and total tissue mass in the anterior and posterior upper leg compartments. Future research should examine reliability measures using a larger sample size and a diverse array of populations across age, body size, body fatness, athletic status, and musculoskeletal development. Future studies may also evaluate the feasibility of examining upper extremity compartmental composition using this novel lateral DXA scanning method to assess potential imbalances. Limitations of examining the upper limbs, however, may include: difficulty in upper extremity lateral positioning on the DXA scanner due to shoulder and forearm rotational differences across individuals; difficulty in delineating the upper arm's anatomically smaller anterior/posterior compartments; and difficulty in obtaining a maximal visible area of soft tissue without head interference. Nonetheless, the ability to assess upper and lower extremity compartmental composition using this study's lateral DXA scanning method may provide a more in-depth analysis for rehabilitative, clinical, and performance purposes.

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Figure 1. Comparison of body composition measures between the (a) total body scan in the frontal view and (b) segmented body scan in the lateral view using ROI boxes. [Note: Proximal and distal ROI borders were placed 60% of the length from the lateral epicondyle to the greater trochanter and lateral malleolus, respectively]

Figure 2.

Left leg DXA scan image with a custom ROI box displaying lateral subject positioning and corresponding body composition measurements for anterior and posterior segmented upper leg compartments.

Table 1
Characteristics of Study Participants

	Male	Female	Total
n	10	11	21
Age (yr.)	20.4±1.4	20.2±1.3	20.3±1.3
Body weight (kg)	90.2±10.3	58.9±3.6	74.0±17.4
Height (m)	1.84±0.09	1.69±0.04	1.77±0.1
BMI (kg/m²)	27.0±3.2	20.7±1.3	23.7±3.9
Percent Body Fat (%)	13.7±3.4	19.2±2.5	16.4±4.1
Total Fat Mass (g)	12206±4144	10966±2000	11586±3230
Total Lean Mass (g)	75514±6526	45965±2112	60739±15877

Abbreviations: BMI, body mass index

Age, body weight, height, BMI, percent body fat, total fat mass, and total lean mass are presented as mean ± SD.

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n = 21 (10 males, 11 females)

Table 2
Frontal and lateral view total leg measures of total, fat, and lean tissue masses, averaged over all study participants

	Male (n=10)	Female (n=11)	Total (n=21)
Right Total Mass (g)			
Frontal (g)	9612±1209	6280±344	8034±1924
Lateral (g)	9559±1148	6321±370	8025±1865
Left Total Mass (g)			
Frontal (g)	9762±1160	6282±445	8114±1987
Lateral (g)	9740±1096	6266±416	8094±1963
Right Fat Mass (g)			
Frontal (g)	1057±502	1075±198	1066±379
Lateral (g)	1015±465	993±336	1004±398
Left Fat Mass (g)			
Frontal (g)	1058±477	1105±203	1080±364
Lateral (g)	1176±616	986±249	1086±476
Right Lean Mass (g)			
Frontal (g)	8110±808	4939±222	6608±1731
Lateral (g)	8160±827	5101±479	6711±1705
Left Lean Mass (g)			
Frontal (g)	8250±734	4898±303	6662±1808
Lateral (g)	8164±549	5052±340	6690±1659

All values reported as mean ± SD.

Note: All measures presented in Table 2 were obtained using an ROI box size of 60% of the length from the lateral epicondyle to the greater trochanter, and 60% of the length from the lateral epicondyle to the lateral malleolus on frontal and lateral view leg scans (See Figure 1a-b).

Table 3
Quantified lateral segmented body measures of total, fat, and lean tissue masses in the separate anterior/posterior upper leg compartments, averaged over all study participants

	Male (n=10)	Female (n=11)	Total (n=21)
Right Total Mass (g)			
Anterior (g)	3088±585	1947±233	2518±728
Posterior (g)	4098±544	2714±294	3406±828
Left Total Mass (g)			
Anterior (g)	2811±557	1887±276	2349±638
Posterior (g)	3876±486	2582±215	3229±758
Right Fat Mass (g)			
Anterior (g)	335±197	331±124	333±160
Posterior (g)	502±294	462±133	482±225
Left Fat Mass (g)			
Anterior (g)	265±150	284±95	275±122
Posterior (g)	441±244	440±144	440±195
Right Lean Mass (g)			
Anterior (g)	2666±464	1568±228	2117±666
Posterior (g)	3481±376	2179±253	2830±737
Left Lean Mass (g)			
Anterior (g)	2449±530	1545±304	1997±626
Posterior (g)	3349±387	2091±239	2720±717

All values reported as mean ± SD.

Note: All measures presented in Table 3 were obtained using an ROI box size of 80% of the length from the lateral epicondyle to the greater trochanter on lateral view upper leg scans (See Figure 2).

Table 4

Inter-rater and intra-rater reliability coefficients of variation for the anterior and posterior compartments of the upper leg and the right and left segmented total upper legs for fat mass, lean mass, and total mass

Measure Compartment	Inter-rater Coefficients						Intra-rater Coefficients					
	Fat (g) CV	Fat (g) ICC	Lean (g) CV	Lean (g) ICC	Total (g) CV	Total (g) ICC	Fat (g) CV	Fat (g) ICC	Lean (g) CV	Lean (g) ICC	Total (g) CV	Total (g) ICC
Right Anterior	2.40	0.998	2.60	0.996	2.64	0.995	1.35	0.999	2.69	0.954	1.51	0.997
Right Posterior	1.88	0.999	3.14	0.986	1.74	0.998	1.75	0.999	1.45	0.997	1.12	0.997
Left Anterior	2.71	0.999	3.52	0.994	3.55	0.991	2.31	0.998	2.31	0.994	2.38	0.991
Left Posterior	2.87	0.998	2.77	0.995	3.12	0.992	1.68	0.999	1.20	0.998	1.33	0.997
Right Total	4.51	0.993	3.19	0.988	3.05	0.986	3.50	0.992	1.91	0.989	2.22	0.984
Left Total	4.80	0.990	3.90	0.985	3.70	0.983	3.85	0.989	2.19	0.988	2.38	0.982

Abbreviations: CV, coefficient of variation; ICC, intra-class correlation coefficient.

Note: "Right Total" and "Left Total" refer to the sum of the anterior and posterior compartments for each measure of each leg (right and left, respectively).