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Validation of pQCT-derived thigh adipose tissue sub-compartments in young girls using a 3 T MRI scanner

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Abstract

Introduction—The ability to assess skeletal muscle adipose tissue is important given the negative clinical implications associated with greater fat infiltration of the muscle. Computed tomography and magnetic resonance imaging (MRI) are highly accurate for measuring appendicular soft tissue and muscle composition, but have limitations. Peripheral quantitative computed tomography (pQCT) is an alternative that investigators find valuable because of its low radiation, fast scan time, and comparatively lower costs. The present investigation sought to assess the accuracy of pQCT-derived estimates of total-, subcutaneous-, skeletal muscle-, intermuscular-, and calculated intramuscular-adipose tissue areas, and muscle density in the mid-thigh of young girls using the gold standard, 3 T MRI, as the criterion.

Methodology—Cross-sectional data were analyzed for 26 healthy girls aged 9 to 12 years. Mid-thigh soft tissue composition was assessed by both pQCT and 3 T MRI. Mean tissue area for corresponding adipose compartments by pQCT and MRI was compared using t-tests, regression analysis, and Bland-Altman plots. Muscle density was regressed on MRI skeletal muscle adipose tissue, intermuscular adipose tissue, and intra-muscular adipose tissue, each expressed as a percentage of total muscle area.

Results—Correlations were high between MRI and pQCT for total adipose tissue ($r^2=0.98$), subcutaneous adipose tissue ($r^2=0.95$), skeletal muscle adipose tissue ($r^2=0.83$), and intermuscular adipose tissue ($r^2=0.82$), and pQCT muscle density correlated well with both MRI skeletal muscle adipose tissue ($r^2=0.70$) and MRI intermuscular adipose tissue ($r^2=0.70$). There was a slight, but statistically significant underestimation by pQCT for total and subcutaneous adipose tissue, while no significant difference was observed for skeletal muscle adipose tissue. Both pQCT-estimated

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intramuscular adipose tissue and muscle density were weakly correlated with MRI-intramuscular adipose tissue.

Conclusions—We conclude that pQCT is a valid measurement technique for estimating all adipose sub-compartments, except for intramuscular adipose tissue, for the mid-thigh region in young/adolescent girls.

Keywords

pQCT; adipose; intermuscular; intramuscular; muscle density; MRI

INTRODUCTION

Skeletal muscle adipose tissue (SMAT) includes all adipose tissue (AT) beneath the fascial planes separating perimysium from subcutaneous AT, including inter- and intra-muscular AT (1). Evidence suggests a strong correlation between higher levels of SMAT and compromised muscle strength (2-6), mobility (5-8), and metabolic function, such as impaired glucose tolerance (9-12), elevated markers of inflammation (12-14), and increased total cholesterol (15, 16). Assessment of SMAT is important given its clinical implications in the elderly and other groups across the age continuum where increased SMAT is associated with poorer health. Evidence suggests that greater muscle fatty infiltration is associated with increased mortality risk (17), a clear indication that developing methods for the accurate assessment of muscle composition is important.

Computed tomography (CT) and magnetic resonance imaging (MRI) are highly accurate for measuring appendicular soft tissue and muscle composition (18), including muscle mass, cross-sectional area and inter- and intra-muscular adiposity measurement (19). However, both methods suffer limited accessibility because of high costs and operational complexity. Further, CT measurements require significant ionizing radiation and patients with metallic implants or medical devices are excluded from MRI. Improvements in field strength, radiofrequency coil design, data acquisition, and pulse sequences, have led to 3 T MRI becoming the criterion for imaging of musculoskeletal tissue (20). Relative to prior MRI's of lower field strengths, 3 T provides an increased signal to noise ratio, higher spatial resolution, enhanced contrast, improved chemical shift resolution, and decreased image acquisition times (20, 21), leading to clear separation of inter- and intramuscular adipose tissue and better overall fat quantification.

Peripheral quantitative computed tomography (pQCT) is an alternative technology. Originally designed for volumetric bone parameters, pQCT has been used to examine changes in muscle composition as the result of disease states and to describe soft tissue associations with frailty (2, 22), bone strength (23, 24), and leg and total body fat (25, 26). Relative to CT and MRI, pQCT's effective radiation dose per scan is minimal ($<1\mu\text{Sv}$), scan time is fast ($<3\text{min/slice}$), and it is inexpensive, making it useful in children as well as adults. Standard manufacturer software provides measures of muscle and fat cross sectional area, as well as muscle density (MD), a distinguishing measure with this densitometer that reflects the amount of fat within the muscle or muscle quality. Sherk et al. compared the cross sectional area of total fat and muscle in the mid-thigh of 9 healthy adults and found no

significant difference between pQCT and MRI (27). While these findings suggest pQCT is accurate for assessment of total adiposity and muscle, evidence of its ability to accurately measure AT sub-compartment areas is lacking.

The present investigation was designed to assess the accuracy of pQCT-derived estimates of total (TAT), subcutaneous (SAT), SMAT, intermuscular (InterAT) and intramuscular AT (IntraAT) areas in the thigh of young girls using the gold standard, 3 T MRI, as the criterion. Normal and overweight/obese girls were measured to assess the effect of body size on accuracy. It was anticipated that pQCT would show strong agreement with MRI for TAT and SAT, but that the AT sub-compartments within the muscle would be measured less accurately because their finer streaks lack the contrast against muscle to be accurately distinguished (28).

MATERIALS AND METHODS

Subjects

Data were analyzed for 26 healthy girls who were participants in the Soft Tissue and Bone Development (STAR) Study. Girls were recruited from elementary and middle schools, community events, and pediatric clinics in Tucson, Arizona. Exclusion criteria included diabetes, medications known to alter body composition, physical disability limiting physical activity, and learning disabilities preventing compliance with assessment protocols. The University of Arizona's Human Subjects Institutional Review Board approved the study and all participants gave written informed assent and parental consent before participation in the study. The study was conducted in accordance with the Helsinki Declaration.

Anthropometry

Standing height and weight measurements were completed with subjects wearing light-weight clothing and no shoes. Height was measured at maximal inhalation to the nearest 0.1 cm using a Schorr measuring board (Schorr Products, Olney, MD). Weight was measured on a calibrated digital scale (model 880; SECA, Hamburg, Germany), accurate to 0.1 kg. The average of two measurements for both height and weight were used as the criterion measurements. BMI was calculated as weight (kg) divided by height squared (m^2). Femur length, following standard protocol (29), was measured in duplicate by 2 separate technicians. Agreement of the 4 measures was required to be within 0.5cm and were repeated as necessary until agreement was achieved. The average of the four measures was used for pQCT assessment.

Dual-energy X-ray Absorptiometry (DXA)

Total body fat percentage was assessed for descriptive purposes using a GE/Lunar Radiation Corp (Madison, WI) Prodigy DXA following standard subject positioning and data acquisition protocols. The within-subject variation for bone and soft tissue in our laboratory on the Lunar Prodigy machine has been previously reported (30). The DXA was calibrated daily according to manufacturer guidelines. One certified technician performed all DXA scan analyses.

pQCT

Soft tissue composition was assessed at the 20% femur (thigh) site relative to the distal growth plate of the non-dominant leg using pQCT (XCT 3000, Stratec Medizintechnik GmbH, Pforzheim, Germany, Division of Orthometrix; White Plains, NY, USA). Two technicians acquired all pQCT scans, and a single investigator performed all scan analyses using Stratec software (Version 6.0). Technicians were trained for pQCT data acquisition and analyses following guidelines provided by Bone Diagnostics, Inc. (Spring Branch, TX, USA). Technicians used a qualitative scale to determine if images had excessive movement and those subjects were not included in the sample for analysis (31). Scout scans were performed to locate the distal growth plate, and parameters were set to find the 20% site from this location. Voxel dimensions were set at 0.4 mm $\times$ 0.4 mm $\times$ 2.3 mm (slice thickness). Scanner speed was set at 25 mm/s. Edge detection and threshold techniques were used to obtain thigh circumference and to separate adipose, muscle, and bone based on their attenuation characteristics, specific to tissue composition and density. Density values for pQCT are established at adipose=0 mg/cm³, muscle=80mg/cm³, and cortical bone=1400 mg/cm³, so thresholds were fixed at 40 mg/cm³ to separate adipose from muscle and at 150 mg/cm³ to separate muscle from bone. Delineation of adipose from muscle was enhanced by first filtering using contour mode 3 (−101 mg/cm³ threshold) and peel mode 2 (40 mg/cm³ threshold) and then with muscle smooth 3, manufacturer image filter (F03F05F05). Subsequent analysis to capture InterAT was performed using ImageJ, a public domain image processing program developed at the National Institutes of Health. Two freehand regions of interest (ROI) were created, an exclusionary one around the femur to eliminate bone and marrow and an inclusionary one placed along the fascial border of the muscle to assess the entire muscle area. Thresholds were then used to separate muscle regions from adipose regions. The adipose area within the ROI was calculated as InterAT area. IntraAT area was estimated by subtracting SAT area and InterAT area (from ImageJ) from the TAT.

MRI

MRI examinations were performed on a 3 T MR system (MAGNETOM Skyra, Siemens Healthcare, Erlangen, Germany) and included the entire thigh region from the base of the patella to the greater trochanter. Imaging was performed using an anterior 18-channel flexible array coil in combination with 12–16 elements of the table-mounted spine array. To estimate fat fractions, we used the 3 three-dimensional (3D) gradient echo pulse sequence (VIBE) with multi-echo acquisition (32, 33). Data were acquired using the following parameters; TR= 9.67 ms, TE1= 1.23 ms, TE2= 2.38 ms, TE3= 4.76 ms, TE4= 5.98 ms, TE5= 7.11 ms, TE6= 8.26 ms, flip angle=6°, acquisition matrix = 256 $\times$ 192, field of view = 380–420 mm, slice thickness= 4 mm, 48 partitions, bandwidth=1300Hz/Pixel. A parallel acceleration technique (CAIPIRINHA) was used with acceleration factors of 2 in both phase encoding and partition directions, leading to an acquisition time of 25 s. Using the slice thickness of 4mm to calculate distance, the slice most closely corresponding to the 20% measurement used in pQCT was used for analysis purposes. In those instances where more than one slice corresponded to the 20% measurement, the mean of those slices was used.

Images were analyzed by a single trained technician using a custom, semi-automated segmentation program (MATLAB R2013A; MathWorks) that set threshold values to

differentiate noise, non-adipose tissue, and adipose tissue. After visual comparison of the original image and the segmented results from the program, the threshold values could be adjusted manually as necessary. Freehand ROIs were used to eliminate femur bone marrow from the non-adipose tissue and to delineate SAT. SMAT area was determined by subtracting the SAT area from total adipose tissue area. For total and all sub-compartment adipose tissue ROIs, the number of respective pixels was multiplied by the pixel size ($1.88\text{mm} \times 1.88\text{mm}$) to yield adipose area (mm^2). The technician repeated analysis in 10 subjects and the intraobserver reliability was good ($\text{ICC}=0.88$). The scans from 24 subjects were also analyzed by a second trained technician to evaluate interrater reliability and showed $\text{ICC}=0.91$.

Statistical Analysis

Statistical analyses were performed using SPSS for Windows, version 24.0 (Chicago, IL). Data are reported as mean $\pm$ SD. Dependent sample *t*-tests were performed to compare MRI and pQCT means for TAT and all AT sub-compartments. Linear regression examined the relationship between MRI- and pQCT-derived TAT and adipose sub-compartment areas. To assess whether pQCT MD is an accurate reflection of AT in skeletal muscle, MD was regressed on MRI SMAT, InterAT and IntraAT expressed as a percentage of total muscle area. Bland Altman analysis was used to examine limits of the agreement (± 2 SEE of differences) between pQCT and MRI areas for all adipose components with 95% confidence intervals (34). To examine the effect of body habitus on differences between MRI and pQCT, BMI and thigh circumference were regressed on the MRI-pQCT difference for each adipose compartment. Pearson's product moment correlation coefficients were calculated for absolute and percent differences for all variables. Significance was set at $p = 0.05$.

RESULTS

Study Sample

Physical characteristics of the sample ($n=26$) are presented in Table 1. Based on U.S. NCHS/CDC age and sex specific percentiles of BMI, where BMI $<85^{\text{th}}$ percentile is normal weight, 85^{th} to $<95^{\text{th}}$ percentile is overweight, and 95^{th} percentile is obese, 13 subjects were normal weight, 6 were overweight, and 7 were obese. MRI and pQCT scans were performed on average within 2 weeks of each other ($1.9 \pm 1.9\text{wk}$).

Thigh Adipose Sub-compartments

Table 2 and Figures 1-5 present comparisons of the different adipose sub-compartments measured by pQCT and MRI.

Total Adipose Tissue (TAT)—Linear regression analysis showed pQCT TAT and MRI TAT were highly correlated ($r^2=0.98$); the difference between the means (305.9mm^2 , $\bar{X}_{\text{diff}} = 5.1\%$) indicated a slight, but significant underestimation by pQCT ($\text{SEE}=346\text{mm}^2$, $\text{SEE}\%=5.9\%$). There was a trend for the underestimation to increase as TAT area, thigh circumference, and BMI increased (Fig 1B-D). Bland Altman analysis (Fig 1B) showed most differences (21 of 26) fell above zero, indicating a positive bias. The percentage error

was 23.6% (95% confidence limit of 1414.6mm² divided by criterion mean TAT 5994.5mm²).

Subcutaneous Adipose Tissue (SAT)—pQCT and MRI estimates of subcutaneous adipose area were highly correlated ($r^2=0.949$) and the difference between the MRI and pQCT SAT means (243.1 mm², $\% \bar{X}_{\text{diff}} = 5.5\%$) indicated a slight, but statistically significant underestimation by pQCT (SEE=389mm², SEE%=9.1%). This underestimation tended to be consistent across the range of thigh circumferences and BMI's (Fig 2C-2D). Bland Altman analysis (Fig 2B) showed a positive bias; the percentage error was 34.4% (95% confidence limit of 1514.3mm² divided by criterion mean SAT 4404.1mm²).

Skeletal Muscle Adipose Tissue (SMAT)—pQCT estimates of SMAT area were well correlated with MRI SMAT area ($r^2=0.83$). Regression analysis showed a slight difference in means (62.8 mm², $\% \bar{X}_{\text{diff}} = 3.9\%$) with an SEE of 239mm² (SEE%=15.3%) as well as proportional bias ($\beta=0.914$, $p=0.00$). The underestimation of SMAT increased as SMAT increased (Fig 3B). The percentage error was 55.3% (95% confidence limit of 878.8mm² divided by criterion mean SMAT 1590.4mm²).

Intermuscular Adipose Tissue (InterAT)—pQCT and MRI estimates of InterAT area were well correlated ($r^2=0.82$). Paired t-tests and regression analysis showed a statistically significant mean difference (167.1 mm², $\% \bar{X}_{\text{diff}} = -17.8\%$) and an SEE of 194mm² (SEE%=19.0%). There was a trend ($p=0.08$) for underestimation of InterAT by pQCT to increase as InterAT area increased (Fig 4B). Bland Altman analysis (Fig 4B) showed the majority (20 of 26) fell below zero, indicating a negative bias. The percentage error was 61.0% (95% confidence limit of 573.4mm² divided by criterion mean InterAT 939.6mm²).

Intramuscular Adipose Tissue (IntraAT)—IntraAT area calculated from pQCT was moderately correlated with MRI IntraAT area ($r^2=0.47$). pQCT significantly underestimated IntraAT area ($\bar{X}_{\text{diff}} = 229.9\text{mm}^2$, $\% \bar{X}_{\text{diff}} = -35.3\%$). Regression analysis indicated proportional bias ($\beta=0.414$, $p=0.036$; SEE=108mm², SEE%=20.2%). The underestimation of pQCT IntraAT increased as IntraAT and BMI increased (Fig 5B, Fig 5D) and there was a trend ($p=0.08$) for underestimation to increase as thigh circumference increased (Fig 5C).

Muscle Density

Figure 6 demonstrates the inverse relationship between pQCT-derived MD and MRI SMAT (Fig 6a), InterAT (Fig 6b) and IntraAT (Fig 6c) as a percentage of the total thigh muscle area. Within the muscle capsule, adipose tissue comprised almost 23% of the area (Table 3). Peripheral QCT MD was well correlated with both SMAT area ($r^2=0.70$) and InterAT area ($r^2=0.70$), but only weakly related to IntraAT area ($r^2=0.20$) (Table 3). This is to be expected because the MD calculation implemented here incorporates the entire muscle capsule, and therefore includes both InterAT and Intra AT.

DISCUSSION

The present study demonstrated strong agreement between TAT area measured by pQCT and MRI in young girls and supports the use of pQCT for measuring AT in the thigh. Our results agree with Sherk et al. who examined TAT area at the mid-thigh of 9 adults of varying age and body habitus (27). The present study extended past work by showing pQCT can be used to estimate most sub-compartments of AT area (SAT, SMAT, InterAT), as well as TAT, and the observed underestimation of TAT and SAT by pQCT is unlikely to affect any clinical conclusion. Given the clinical implications of compromised strength (2-6), mobility (5-8), and metabolic function associated with higher AT depots [2-28] and evidence linking increased fatty infiltration of the muscle with increased mortality risk (17), validation of pQCT to assess and track muscle adipose tissue is an important finding.

MD, which incorporates both InterAT and IntraAT in its calculation, has been the customary way pQCT is used to evaluate muscle tissue quality in the limbs. The present study supports the use of pQCT derived MD as a surrogate measurement to SMAT, and even InterAT, given the relationship observed between these variables and MD. This agrees with Wong et al. who validated pQCT MD as a proxy for SMAT measurements within the lower leg muscles of women 50 years of age using pMRI, where SMAT area explained 50% of MD variance (22). As expected, MD had only a weak correlation with IntraAT, likely due to the inclusion of both InterAT and IntraAT in the estimate of MD, plus the fact that IntraAT contributes significantly less to the relative percentage of muscle fat compared to InterFat. It is possible that our technique using an indirect calculation to attain IntraAT area could also decrease the correlation. Also, the relative homogeneity of IntraAT in the current population lowered the correlation. Girls 9-12 years of age are not yet likely to vary greatly in the fatty infiltration seen later in life, limiting the observable range.

Peripheral QCT experiences a weakened signal to noise ratio as the diameter of limbs increases. Consequently, we predicted that available body habitus variables such as BMI and thigh circumference would have an effect on pQCT's ability to accurately measure thigh adiposity. Only IntraAT was significantly impacted by these variables, and only by BMI, as pQCT underestimation increased as BMI increased. Other than this, the results suggest that the pQCT's accuracy was not significantly affected by size. There was, however, a trend toward increasing differences and weaker agreement as BMI and thigh circumference increased. Examining a range of sizes was important for the generalizability of the study, but a future study with a controlled range of thigh circumferences could further assess the precision of pQCT-derived soft tissue estimates.

While CT and MRI are the preferred methods for capturing thigh adiposity, this study shows that pQCT provides a viable alternative. In fact, pQCT may provide an advantage over these methods in certain circumstances, given its lower purchase price, lower cost per scan, and fewer operational skills. In situations where patient exposure to ionizing radiation is of concern, pQCT's minimal effective dose makes it the preferred option. Similarly if studying a population where metallic implants or non-removable medical devices are involved, pQCT provides an alternate method.

The high cost of MRI limited our sample size, which was a limitation of our study. Although an a priori statistical power analysis was not performed, our sample was nearly three times larger than the sample examined in the only other study to compare adipose compartments of the thigh (27). The sample provided a range of body sizes for comparison to help understand the impact of signal noise. However, the restricted age range may have diminished the variability in fatty infiltration of the muscle. A more variable age range and larger sample would allow for greater generalizability, but one could expect that the slight AT underestimation would be similar with an increased sample size. There is a tendency for childhood obesity to persist with advancing age (35), and while the overall quantity of adipose tissue may increase in adulthood, the process of quantifying tissues by pQCT (i.e. identifying individual voxels as adipose, muscle, or bone based on tissue density) remains the same, so one might expect the accuracy to persist across populations. While the manufacturer software used here showed strong agreement, it is unknown if using an alternative analysis technique, such as the watershed algorithm described by Wong et al. (35), would have resulted in stronger relationships between the pQCT and MRI adiposity measures. Nevertheless, this first investigation to assess the accuracy of pQCT using a 3 T MRI provides investigators with a better understanding of pQCT's viability for measuring appendicular soft tissue and muscle composition.

CONCLUSIONS

We show pQCT is a valid alternative to CT and MRI for estimating TAT and the adipose sub-compartments of SAT, SMAT, and InterAT for the mid-thigh region in young/adolescent girls. Total AT and SAT are slightly underestimated by pQCT. Muscle density, as generated from pQCT, can be used as a surrogate to SMAT.

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Figure 1.

(A) Total adipose tissue pQCT vs MRI, solid line indicates line of identity; (B) Bland Altman plot of MRI-pQCT total adipose tissue difference against average of MRI and pQCT; (C) Plot of MRI-pQCT total adipose tissue difference against thigh circumference; (D) Plot of MRI-pQCT total adipose tissue difference against BMI. B-D: Solid line indicates mean difference and large dashed lines indicate ± 2 SD.

Figure 2.

(A) Subcutaneous adipose tissue pQCT vs MRI, solid line indicates line of identity; (B) Bland Altman plot of MRI-pQCT subcutaneous adipose tissue difference against average of MRI and pQCT; (C) Plot of MRI-pQCT subcutaneous adipose tissue difference against thigh circumference; (D) Plot of MRI-pQCT subcutaneous adipose tissue difference against BMI. B-D: Solid line indicates mean difference and large dashed lines indicate ± 2 SD.

Figure 3.

(A) Skeletal muscle adipose tissue pQCT vs MRI, solid line indicates line of identity; (B) Bland Altman plot of MRI-pQCT skeletal muscle adipose tissue difference against average of MRI and pQCT; (C) Plot of MRI-pQCT skeletal muscle adipose tissue difference against thigh circumference; (D) Plot of MRI-pQCT skeletal muscle adipose tissue difference against BMI. B-D: Solid line indicates mean difference and large dashed lines indicate ± 2 SD.

Figure 4.

(A) Intermuscular adipose tissue pQCT vs MRI, solid line indicates line of identity; (B) Bland Altman plot of MRI-pQCT intermuscular adipose tissue difference against average of MRI and pQCT; (C) Plot of MRI-pQCT intermuscular adipose tissue difference against thigh circumference; (D) Plot of MRI-pQCT intermuscular adipose tissue difference against BMI. B-D: Solid line indicates mean difference and large dashed lines indicate $\pm 2 \text{ SD}$.

Figure 5.

(A) Intramuscular adipose tissue pQCT vs MRI, solid line indicates line of identity; (B) Bland Altman plot of MRI-pQCT intramuscular adipose tissue difference against average of MRI and pQCT; (C) Plot of MRI-pQCT intramuscular adipose tissue difference against thigh circumference; (D) Plot of MRI-pQCT intramuscular adipose tissue difference against BMI. B-D: Solid line indicates mean difference and large dashed lines indicate ± 2 SD.

Figure 6.

Plots of pQCT-derived thigh muscle density against (A) thigh skeletal muscle adipose tissue area from MRI, (B) thigh intermuscular adipose tissue area from MRI, and (C) thigh intramuscular adipose tissue area from MRI. Solid line indicates line of identity.

Table 1

Sample Characteristics (n=26)

	Mean	SD	Range
Age (yr)	11.0	1.3	9.3 – 12.9
Weight (kg)	45.8	11.8	27.5 – 74.6
Height (cm)	147.1	9.4	132.0 – 161.7
BMI (kg/m ²)	21.0	4.4	15.3 – 32.7
BMI Percentile	70.6	27.8	21.9 – 99.6
Total Body Fat Percentage	34.8	9.0	17.1 – 49.0
Thigh Variables			
Circumference (mm)	361.8	47.5	288.7 – 477.7
Muscle Density (pQCT)	77.9	1.6	75.0 – 80.3
TAT Area (pQCT)(mm ²)	5688.5	2265.9	1887.0 – 10730.1
TAT Area (MRI)(mm ²)	5994.4	2363.9	2525.0 – 11836.1
SAT Area (pQCT)(mm ²)	4160.9	1727.9	1415.0 – 7831.2
SAT Area (MRI)(mm ²)	4404.1	1744.7	1957.8 – 9077.3
SMAT Area (pQCT)(mm ²)	1527.6	578.1	472.0 – 2940.6
SMAT Area (MRI)(mm ²)	1590.4	690.3	566.6 – 3311.2
SMAT from MRI (% of muscle area)	22.8	7.7	10.7 – 38.1
InterAT Area (pQCT)(mm ²)	1106.7	453.8	322.6 – 2167.8
InterAT Area (MRI)(mm ²)	939.6	530.1	167.0 – 2135.6
InterAT from MRI (% of muscle area)	13.4	6.7	3.3 – 26.5
IntraAT Area (pQCT)(mm ²) *	420.9	148.4	149.4 – 822.1
IntraAT Area (MRI)(mm ²)	650.8	204.3	393.3 – 1175.6
IntraAT from MRI (% of muscle area)	9.4	1.6	6.0 – 13.4

TAT = Total Adipose Tissue; SAT = Subcutaneous Adipose Tissue; SMAT = Skeletal Muscle Adipose Tissue; InterAT = Intermuscular Adipose Tissue; IntraAT = Intramuscular Adipose Tissue

* Intramuscular Adipose Tissue Area from pQCT estimated by subtracting subcutaneous adipose tissue area (pQCT) and intermuscular adipose tissue area (pQCT) from total adipose tissue area (pQCT)

Table 2

Mean comparisons of pQCT and MRI for thigh adipose tissue subcompartments

	Mean (mm ²)	Mean Difference (%)	Adjusted R Square	SEE	SEE %	Standardized Beta	Sig
a) Thigh Subcompartment Area							
pQCT TAT Area (mm ²)	5688.5	5.10 *	0.98	346	5.9	0.99	< 0.001
MRI TAT Area (mm ²)	5994.4						
pQCT SAT Area (mm ²)	4160.9	5.52 *	0.95	390	9.1	0.98	< 0.001
MRI SAT Area (mm ²)	4404.1						
pQCT SMAT Area (mm ²)	1527.6	3.95	0.83	239	15.3	0.91	< 0.001
MRI SMAT Area (mm ²)	1590.4						
pQCT InterAT Area (mm ²)	1106.7	-17.78 *	0.82	194	19.0	0.91	< 0.001
MRI InterAT Area (mm ²)	939.6						
pQCT IntraAT Area (mm ²)	420.9	35.33 *	0.47	108	20.2	0.70	< 0.001
MRI IntraAT Area (mm ²)	650.8						

TAT = Total Adipose Tissue; SAT = Subcutaneous Adipose Tissue; SMAT = Skeletal Muscle Adipose Tissue; InterAT = Intermuscular Adipose Tissue; IntraAT = Intramuscular Adipose Tissue

* Significant difference (p < 0.05) between MRI and pQCT by dependent samples t-test

Table 3

Regression of pQCT-derived muscle density on MRI muscle adipose tissue areas

	Mean	Adjusted R Square	SEE	Standardized Beta	Sig
pQCT Muscle Density (mg/cm ³)	77.88	0.69	0.91	-0.84	0.00
MRI SMAT (% Muscle Area)	22.79				
pQCT Muscle Density (mg/cm ³)	77.88	0.70	0.91	-0.84	0.00
MRI InterAT (% Muscle Area)	13.36				
pQCT Muscle Density (mg/cm ³)	77.88	0.20	1.47	-0.48	0.01
MRI IntraAT (% Muscle Area)	9.43				

SMAT = Skeletal Muscle Adipose Tissue; InterAT = Intermuscular Adipose Tissue; IntraAT = Intramuscular Adipose Tissue