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Estimating whole body intermuscular adipose tissue from single cross-sectional magnetic resonance images

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Abstract

Estimating whole body intermuscular adipose tissue from single cross-sectional magnetic resonance images. Intermuscular adipose tissue (IMAT), a novel fat depot linked with metabolic abnormalities, has been measured by whole body MRI. The cross-sectional slice location with the strongest relation to total body IMAT volume has not been established. The aim was to determine the predictive value of each slice location and which slice locations provide the best estimates of whole body IMAT. MRI quantified total adipose tissue of which IMAT, defined as adipose tissue visible within the boundary of the muscle fascia, is a subcomponent. Single-slice IMAT areas were calculated for the calf, thigh, buttock, waist, shoulders, upper arm, and forearm locations in a sample of healthy adult women, African-American [$n = 39$; body mass index (BMI) $28.5 \pm 5.4 \text{ kg/m}^2$; $41.8 \pm 14.8 \text{ yr}$], Asian ($n = 21$; BMI $21.6 \pm 3.2 \text{ kg/m}^2$; $40.9 \pm 16.3 \text{ yr}$), and Caucasian ($n = 43$; BMI $25.6 \pm 5.3 \text{ kg/m}^2$; $43.2 \pm 15.3 \text{ yr}$), and Caucasian men ($n = 39$; BMI $27.1 \pm 3.8 \text{ kg/m}^2$; $45.2 \pm 14.6 \text{ yr}$) and used to estimate total IMAT groups using multiple-regression equations. Midthigh was the best, or near best, single predictor in all groups with adjusted R^2 ranging from 0.49 to 0.84. Adding a second and third slice further increased R^2 and reduced the error of the estimate. Menopausal status and degree of obesity did not affect the location of the best single slice. The contributions of other slice locations varied by sex and race, but additional slices improved predictions. For group studies, it may be more cost-effective to estimate IMAT based on one or more slices than to acquire and segment for each subject the numerous images necessary to quantify whole body IMAT.

Keywords

race; body composition; fat distribution; muscle fat; imaging

Adipose tissue and its distribution are risk factors for metabolic abnormalities (4,13,15,19, 24,29). There is a need to quantify the size of specific adipose tissue compartments in vivo and to relate this information to metabolic risk factors and function. Invasive measures have been replaced by noninvasive imaging techniques that are safe and do not disturb the internal

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DISCLOSURES

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medium. Recent advances in MRI have allowed investigators to quantify, at the whole body level, total adipose tissue (TAT) and its subcompartments, subcutaneous (SAT), visceral (VAT), and intermuscular adipose tissue (IMAT). Although whole body measures are desirable when investigating systemic conditions or diseases, it is not always practical or feasible for investigators to acquire a whole body MRI scan. A shorter protocol involving fewer slices is often desirable.

Our laboratory recently described an IMAT depot located between muscle bundles, as measured on whole body MRI (7,31). IMAT is defined as the adipose tissue visible on MRI images between muscle groups and beneath the muscle fascia. Subsequently, Albu et al. (1) found, in premenopausal African-American women who had significantly higher insulin resistance and acute insulin response to glucose than did their white counterparts, that whole body IMAT, but not VAT or SAT, was an important independent correlate of insulin resistance. Previously, IMAT in a single midthigh slice measured by computed tomography (CT) showed that insulin resistance was associated with increased subfascial adipose tissue in obese adults (10) and thinner older persons (11). Goodpaster and colleagues (10) also found that adipose tissue located beneath the fascia lata and, therefore, adjacent to skeletal muscle (SM), was significantly negatively correlated with insulin resistance, whereas adipose tissue located above the fascia (i.e., SAT) and removed from SM was not (10). Therefore, this depot is potentially important in understanding metabolic disease.

A comprehensive evaluation of whole body IMAT requires a whole body MRI or CT scan. Since acquiring a whole body scan demands considerable resources, including time required of subject in the scanner, costs of acquisition and image analyses, and for CT the issue of large radiation dose, a question arises as to whether it might be preferable or more cost effective to use one or more cross-sectional slices or combination of slices to estimate whole body IMAT in lieu of a whole body IMAT scan. Such a decision requires information on the predictive value of a subset of slices. The primary aim of this study was to determine which slice location, or combination of slice locations, provides the best estimates of whole body IMAT and to quantify the predictive value of these slice locations.

METHODS

Subjects

Subjects were independent, community-dwelling African-American, Asian, and Caucasian women and men (≥ 18 yr) who had participated in one of five studies at St. Luke's-Roosevelt Hospital's Body Composition Unit between 1996 and 2002. Recruitment occurred through advertisements in newspapers and flyers posted in the local community. Inclusion criteria for all studies required that subjects be ambulatory, weight stable (± 2 kg over past 6 mo), nonexercising based on self-report of no participation in vigorous routine or structured exercise, and nonsmoking. Race was determined by self-report according to the following criteria. All parents and grandparents were required to be of the same race: non-Hispanic African-American and non-Hispanic Caucasian, for African-American and Caucasian subjects, respectively. Asians were required to report all parents and grandparents as being of Eastern Asian origin.

Each subject completed a medical examination, and the majority of subjects had screening blood tests after an overnight fast that included a standard hematology and blood chemistry panel. Subjects with untreated diabetes mellitus, malignant/catabolic conditions, missing limb, who had had joint replacement, those currently taking estrogen replacement therapy, and those taking medications that could potentially influence body composition were excluded from the study. Menopausal status was determined by self-report of menses. Women who had not

menstruated within the past year were considered postmenopausal. All studies were approved by the Institutional Review Board, and all subjects gave written consent to participate.

Body Composition

Subjects reported in the morning in a fasted state to the Body Composition Laboratory. With the subject wearing a hospital gown and foam slippers, body weight and height were measured to the nearest 0.1 kg (Weight Tronix, New York, NY) and 0.5 cm (Holtain Stadiometer, Crosswell, UK), respectively (8).

MRI

Acquisition—Subjects were placed on the 1.5-T scanner (General Electric, 6X Horizon, Milwaukee, WI) platform with their arms extended above their heads. The protocol involved the acquisition of ~40 axial images, 10-mm thickness, and at 40-mm intervals across the whole body (26). The scanning protocol commenced at the L₄–L₅ intervertebral space in all subjects, and the lower body was scanned first. Thereafter, the L₄–L₅ position was relocated, and the upper body was scanned with arms outstretched above the head. Total body SM and TAT mass, including total SAT, VAT, and IMAT, was measured from the whole body multislice MRI. Individual slices located closest to the widest calf, midthigh, widest buttock, waist (L₄–L₅ interspace), shoulders, mid-upper arm, and mid-forearm were extracted from the whole body scan, and IMAT, SAT, and SM areas (cm²) within these slices were determined.

Analysis—SliceOmatic 4.2 image analysis software (Tomovision, Montreal, Canada) was used to analyze images on a PC workstation (Gateway, Madison, WI) at the Image Reading Center (New York, New York). IMAT in our laboratory is defined as IMAT that is visible between muscle groups and beneath the muscle fascia, as previously described (31) (Fig. 1). MRI volume estimates were converted to mass using the assumed density of 1.04 kg/l for SM and 0.92 kg/l for adipose tissue (30). All scans were read by the same analyst (P. Kuznia). The technical errors for four repeated readings of the same four whole body scans by the same observer (P. Kuznia) of MRI-derived SM, SAT, VAT, and IMAT volumes in our laboratory are 1.4, 1.7, 2.3, and 5.9%, respectively.

Data Analysis

Descriptive statistics were calculated for the study sample. Data are presented as means $\pm$ SD with ranges in the text, unless otherwise stated. Differences among the race/sex groups were determined using an analysis of variance. Homogeneity of residual variances was established by Levene's test. If variances were unequal, then the Brown-Forsythe *F* was used to test equality of means and post hoc comparisons used Dunnett's *C* test. Otherwise, equality of means was tested with the usual *F* ratio, and subsequent comparisons of means used the REGW-F range test. Pearson correlation coefficients were used to assess the bivariate linear relationships of all the single slices with age, weight, height, IMAT, and TAT. Linear regression analysis was used to assess the relation between independent variables (single slice from calf, thigh, buttocks, waist, shoulders, upper arm, and forearm) and the dependent variable (whole body IMAT volume). Regression equations were cross-validated using the method of deleted residuals (6). Data were split by sex and race because significant interactions between racial group and sex were found. Adjusted *R*² was used as a measure of the strength of the relationship in multiple regressions. Exploratory analyses were conducted to investigate whether optimal slice location differed by menopausal status and degree of obesity [median split on body mass index (BMI)] by testing the significance of differences between correlated correlations using the method of Steiger (32). In all analyses, a two-tailed α -level of 0.05 was used. Data were analyzed using SPSS version 13.0 (SPSS Institute, Chicago, IL).

RESULTS

Subject Characteristics

The descriptive characteristics of the sample are summarized in Table 1. Among the female groups, the African-American women had the highest mean BMI (kg/m^2), weight, SM, TAT, and IMAT; the Asian women had the lowest values; and the Caucasian women were intermediate. Compared with all women, the Caucasian men were significantly taller, heavier, and had more SM mass.

Slice Location in Relation to Total Body IMAT

To determine which slice best predicts total body IMAT, the correlations between the single-slice IMAT areas and total body IMAT volume were examined. They ranged between $r = 0.44$ and 0.86 (African-American women), $r = 0.21$ and 0.72 (Asian women), $r = 0.37$ and 0.81 (Caucasian women), and $r = 0.35$ and 0.92 (Caucasian men), and are summarized in Table 2. The highest correlations between a single-slice IMAT area and IMAT volume were located at the midthigh (African-American women, $r = 0.86$, Caucasian women, $r = 0.86$, and Caucasian men, $r = 0.86$) and midcalf (Asian women, $r = 0.72$), respectively (Fig. 2). The highest correlations between a single-slice IMAT area and TAT volume were also found at the same slice locations as for total IMAT: midthigh slice (African-American women $r = 0.67$, Caucasian women $r = 0.60$, and Caucasian men $r = 0.72$) and midcalf (Asian women $r = 0.76$). The relationship of total body IMAT to a single midthigh slice area was found to differ by group (interaction $P = 0.04$); therefore, all subsequent analyses were performed separately for each sex/race group.

We investigated whether the variation in selection of best location that was seen in Asians and in subgroup analyses of menopausal status and obesity was statistically reliable. A median split on BMI did not affect the choice of midthigh as the best location for Caucasian men or women, although, in the low BMI group of African-American women, the waist had a slightly higher correlation than midthigh (0.88 vs. 0.80). Menopausal status did not change the location of the best slice for African-American women or Caucasian premenopausal women, but in Caucasian postmenopausal women buttocks had a slightly higher correlation and thigh was second best (0.81 vs. 0.79). When a location other than midthigh had a higher correlation with IMAT than midthigh, statistical tests did not find the difference in strength of association to be significant (all $P > 0.10$).

Prediction Models for Total Body IMAT Volume

The single-slice IMAT areas (in cm^2) of the calf, thigh, buttocks, waist, shoulders, upper arm, and forearm were included in linear regression models as independent variables, with total body IMAT volume (in liters) as the dependent variable. The coefficients for the developed regression equations using one, two, and three independent variables are shown in Table 3. The standard error of the estimate for a single slice or combined slices derived from the stepwise regression models ranged from 0.15 to 0.36 liter. In every case, the addition of a second and third slice reduced the standard error of the estimate and increased the amount of variance accounted for, making a statistically significant improvement in the prediction. The adjusted R^2 ranged from 0.49 to 0.92 . Although midthigh was not the best single-slice location for Asian women, we have included in Table 3, for comparability with the other groups, the coefficients for the regression of total body IMAT on midthigh slice as the first variable.

DISCUSSION

The correlations between calf, thigh, buttocks, shoulders, upper arm, and forearm cross-sectional areas, and total body IMAT volumes and TAT, were examined in different race and

sex groups. We found the highest correlations between single-slice IMAT areas and total body IMAT volumes were at midhigh (African American women, Caucasian women, and Caucasian men) and midcalf (Asian women). Because of the small size of the Asian sample and somewhat different characteristics of this group (shorter, lighter), we cannot be confident that the finding of different optimal location for Asian women is reliable. Also, subgroup analyses by menopause status and degree of obesity did not find, within the limits of the power of this sample, evidence for a different optimal location of the best single slice. The improvement in predictive power from adding a second and third slice and the locations of the best slices to add can be seen in Table 3.

As the prevalence of obesity increases world wide, it is well recognized that excess adiposity is associated with heart disease, stroke, hypertension, and Type 2 diabetes (4,5,11,14,21,28, 35). Several studies have reported an association between IMAT and metabolic abnormalities (12,16,26,27,31,33). One potential mechanism of action linking IMAT with insulin signaling is through triacylglycerol metabolites interfering with insulin signaling transduction, thereby altering whole body glucose and lipid metabolism. Therefore, for researchers investigating the relation of health risk with fat deposits, it may be of interest to estimate total body IMAT or to identify a good surrogate measure. Since the measurement of total body IMAT is costly in terms of time and resources, estimates made from one or more slices using the regression equations of Table 3 may serve the investigator's purpose.

Most previous studies of IMAT have utilized a single midhigh slice by CT (9,10,27). Although this methodology also quantifies IMAT cross-sectional area in the midhigh slice, the physical principals on which MRI and CT are based are very different; thus there is no assurance that the IMAT areas identified are equivalent (23). There are no studies showing how well total body IMAT is captured by a single CT slice. A first step toward assessing the interchangeability of these methods would be to evaluate the degree of agreement in IMAT areas from single CT and MRI midhigh slices.

It is well known that the reliability of a measure affects the number of cases needed to detect an effect of a particular size, so it is of interest to estimate the number of cases with single-or multiple-slice IMAT data that would be needed to obtain statistical power equivalent to that which would have been obtained by measuring total body IMAT (22). The adjusted R^2 from the single- and multiple-slice regressions may be interpreted as a reliability coefficient (R) in the measurement of total body IMAT in that it provides an estimate of how much between-subject variability is accounted for by the regressors. If N is the sample size necessary to detect an effect under perfect reliability ($R = 1$), then the necessary sample size (N') under reduced reliability ($R < 1$) is N/R (18). Thus, for example, if the multiple-slice whole body IMAT is taken as a measure of the true IMAT volume, and a single-slice $R^2 = 0.75$, then equivalent power would be achieved by measuring single slices in one-third more cases. The attractiveness of this option will depend on the relative cost of enrolling additional subjects vs. that for acquiring and analyzing additional measurements. Investigators can easily make an approximate calculation of these costs for a planned study at a specific facility; those wishing to make more comprehensive and rigorous calculations can consult the literature on cost-effective research design (2,20). Investigators who already have acquired single-slice MRI images at the appropriate locations in their physiological research might use our models to make estimates of total body IMAT, bearing in mind the limitations of the sampling method and the sample size.

The locations of the highest correlations between single-slice IMAT area and total body adipose tissue volumes were identical to those for total IMAT: midhigh for African American women, Caucasian women, and Caucasian men, and midcalf for Asian women.

MRI Measurement Issues

MRI depends on the density of hydrogen nuclei and the relaxation time of the tissue to separate different tissues of interest. The visual appearances of SM and adipose tissue in an image are strikingly different (33). IMAT is attempting to quantify the adipose tissue located between the muscle bundles. We adopted a standard protocol, where comparisons of MRI with corresponding cadaver analysis of leg and arm sections showed a high correlation ($r = 0.92$, $P < 0.001$) for IMAT (17). Use of this protocol, coupled with the advantage of a single reader analyst, reduced the variability in IMAT measurement.

Study Limitations

The exact location of each slice above or below the L₄–L₅ position is influenced by height of the subject, and each slice may not be anatomically identical across subjects. All components of body composition, including IMAT, are potentially influenced by dietary intake, levels of physical activity and/or inactivity, and exercise, for which no independent measures were acquired. This study used a convenience sample of urban-dwelling healthy African-American women, Asian women, and Caucasian women and men and cannot be considered representative of the general adult population. Although the relationships between variables (single slice-total IMAT) found in this sample should hold in other samples of healthy subjects, extrapolation of these findings to other samples should be made with caution. Also, the amount of variance accounted for by the regressions in this study may overstate their predictive value, since the slice locations were not specified a priori. The presence of unreported and undiagnosed medical conditions that could affect body composition cannot be ruled out. Race group was determined by self-report, which is reported to be a suitable proxy for genetic ancestry, especially when assessing disease risk (25), but does not take into account degrees of admixture. It is also possible, given the significant differences in BMI among the ethnic subgroups in our sample, that the variables in our models do not adequately take into account the differences in BMI.

In addition, further studies are needed to confirm our findings in patients with health-related disorders. Our developed models are based on healthy ambulatory adults, and therefore our models may not be accurate when applied to subjects with disproportional muscle growth or atrophy or following soon after significant weight change. Another limitation is that we had a relatively small number of Asian women, so that our findings for this group should be viewed cautiously.

Study Strengths

We had available for this study a sample of African-American, Asian, and Caucasian women and Caucasian men whose total body IMAT had been measured by MRI and were able to evaluate the representative value of different slice locations (from continuous scans across the whole body) rather than assuming that a single thigh slice, as used in previous studies, was the best location. One MRI reader analyzed all scans for IMAT, including a subset reread over time to establish intrareader variability. All scans were acquired in one center under high levels of quality control by well-trained examiners skilled in performing a protocol for body composition measurements.

In conclusion, single cross-sectional images at midthigh had the highest correlation of IMAT area with whole body IMAT volume in a sample of African American women, Caucasian women, and Caucasian men. In view of the relatively high correlations, for group studies it may be more cost-effective to estimate IMAT based on one or more slices than to acquire and segment numerous images necessary to quantify whole body IMAT. (3,34)

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T. Harris and D. Gallagher provided the current study concept. J. Albu, D. Gallagher, and S. Heymsfield provided data. P. Kuznia provided MRI analyses. X. Y. Ruan, S. Heshka, and D. Gallagher provided analysis and interpretation of data. J. Albu, D. Gallagher, T. Harris, S. Heshka, and X. Y. Ruan provided critical review of manuscript for intellectual content. S. Heshka provided statistical expertise. T. Harris and D. Gallagher obtained funding. D. Gallagher and T. Harris provided study supervision. We acknowledge the contributions of Mark Punyanitya, the Director of the Image Reading Center where MRI analyses were performed.

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Fig. 1. Cross-sectional images from the midthigh in a female participant (age 72 yr). *Top*: MRI gray scale image; *bottom*: corresponding analyzed images. Pink, intermuscular adipose tissue; red, skeletal muscle; green, subcutaneous adipose tissue.

Fig. 2.

Total body intermuscular adipose tissue (IMAT) predicted from a single IMAT slice shown in relation to IMAT (in liters). Linear regression lines are shown for Caucasian women (long dashed line), African-American women (short dashed line), Asian women (thick solid line), and Caucasian men (thin solid line). All slopes were significantly difference from zero ($P < 0.05$). All intercepts were significantly difference from zero ($P < 0.01$). *, Caucasian women: $\text{IMAT} = 0.38 + 15.5 \times \text{midthigh IMAT}$ [SE of the estimate (SEE) = 0.29 liter, adjusted $R^2 = 0.73$, $n = 43$]. □, African-American women: $\text{IMAT} = 0.53 + 10.4 \times \text{midthigh IMAT}$ (SEE = 0.36 liter, adjusted $R^2 = 0.74$, $n = 39$). △, Asian women: $\text{IMAT} = 0.67 + 160.2 \times \text{midcalf IMAT}$ (SEE = 0.27 liter, adjusted $R^2 = 0.49$, $n = 21$). ●, Caucasian men: $\text{IMAT} = 0.27 + 13.8 \times \text{midthigh IMAT}$ (SEE = 0.21 liter, adjusted $R^2 = 0.84$, $n = 39$).

Table 1
Body composition characteristics of study subjects

	African-American Women	Asian Women	Caucasian Women	Caucasian Men
<i>n</i>	39	21	43	39
Age, yr	41.8±14.8 ^a (22–87)	40.9 ± 16.3 ^a (20–81)	43.2± 15.3 ^a (19–81)	45.2±14.6 ^a (19–74)
Height, m	1.64±0.06 ^a (1.5–1.8)	1.59±0.05 ^b (1.49–1.73)	1.64±0.06 ^a (1.45–1.78)	1.79±0.07 ^c (1.60–1.91)
Weight, kg	76.9 ± 15.9 ^a (47.3–107.0)	54.9 ±10.5 ^b (40.8–78.0)	68.3±13.9 ^a (42.3–101.9)	86.8 ±10.9 ^c (69.6–114.0)
Body mass index, kg/m ²	28.5±5.4 ^a (17.7–38.6)	21.6±3.2 ^b (17.5–29.2)	25.6±5.3 ^a (15.9–39.0)	27.1 ±3.8 ^a (20.0–38.6)
Skeletal muscle, kg	23.1 ±3.4 ^a (16.4–30.7)	16.4±2.2 ^b (12.6–20.4)	20.4±2.8 ^c (14.6–29.5)	33.9±4.7 ^d (25.3–46.1)
Total adipose tissue, kg	30.8±11.6 ^a (8.2–51.8)	18.6±7.8 ^c (9.1–38.5)	25.6±11.2 ^b (8.6–19.5)	23.5±8.1 ^{b,c} (10.1–40.5)
Intermuscular adipose tissue, kg	1.3 ±0.6 ^b (0.3–2.6)	0.8±0.4 ^a (0.2–1.4)	1.0±0.5 ^a (0.3–2.1)	0.9±0.5 ^a (0.2–1.8)
Intermuscular adipose tissue, liters	1.4±0.7 ^b (0.3–2.9)	0.8±0.4 ^a (0.2–1.5)	1.1±0.6 ^a (0.3–2.2)	0.9±0.5 ^a (0.2–2.0)
Calf, * cm ²	0.01 ±0.01 ^a (0.00–0.05)	0.001 ±0.002 ^b (0.00–0.005)	0.004±0.006 ^c (0.000–0.024)	0.01 ±0.005 ^c (0.00–0.00)
Thigh, * cm ²	0.09±0.06 ^b (0.01–0.24)	0.03 ± 0.02 ^a (0.01–0.07)	0.04±0.03 ^a (0.00–0.11)	0.05±0.03 ^a (0.00–0.12)
Buttock, * cm ²	0.04±0.03 ^a (0.00–0.10)	0.04±0.03 ^a (0.00–0.11)	0.05 ± 0.03 ^a (0.00–0.14)	0.03 ±0.04 ^a (0.00–0.19)
Waist L4–L5, * cm ²	0.02±0.02 ^{a,b} (0.00–0.12)	0.01 ±0.02 ^{a,b} (0.00–0.06)	0.02±0.02 ^a (0.00–0.10)	0.01 ±0.01 ^b (0.00–0.04)
Shoulder, * cm ²	0.03 ±0.02 ^a (0.00–0.08)	0.02±0.02 ^b (0.00–0.07)	0.02±0.02 ^b (0.00–0.08)	0.01 ±0.01 ^c (0.00–0.03)
Upper arm, * cm ²	0.01 ±0.01 ^{a,c} (0.00–0.05)	0.007 ±0.005 ^{b,c} (0.00–0.02)	0.006±0.006 ^b (0.000–0.023)	0.007 ±0.007 ^{b,c} (0.000–0.025)
Forearm, cm ²	0.005 ±0.004 ^b (0.00–0.02)	0.002±0.002 ^a (0.00–0.01)	0.002±0.003 ^a (0.00–0.01)	0.003 ±0.002 ^a (0.000–0.007)

Values are means ± SD with ranges in parentheses; *n*, no. of subjects.

^{a,b,c} Means not sharing a common superscript letter are significantly different at $P < 0.05$ based on post hoc multiple comparisons; REGW-F for equal and Dunnett *C* test for unequal variances.

* Cross-sectional area of intermuscular adipose tissue in single slice at this location.

Table 2
Intermuscular adipose tissue slice Pearson correlations

	Women			Men
	African-American	Asian	Caucasian	Caucasian
<i>N</i>	39	21	43	39
Calf vs.				
Age, yr	0.27	0.38	0.21	0.42 [†]
Body weight, kg	0.43 [†]	0.74 [†]	0.56 [†]	0.23
Height, m	0.05	0.53 [*]	0.08	-0.05
IMAT, kg	0.72 [†]	0.72 [†]	0.69 [†]	0.61 [†]
TAT, kg	0.49 [†]	0.76 [†]	0.50 [†]	0.41 [†]
Thigh vs.				
Age, yr	0.04	-0.15	0.21	0.34 [*]
Body weight, kg	0.56 [†]	0.36	0.55 [†]	0.57 [†]
Height, m	0.03	0.44 [*]	0.05	-0.32 [*]
IMAT, kg	0.86 [†]	0.57 [†]	0.86 [†]	0.92 [†]
TAT, kg	0.67 [†]	0.35	0.60 [†]	0.72 [†]
Buttock vs.				
Age, yr	0.37 [*]	0.63 [†]	0.52 [†]	0.33 [*]
Body weight, kg	0.26	0.22	0.45 [†]	0.23
Height, m	-0.11	-0.10	0.00	-0.04
IMAT, kg	0.70 [†]	0.43	0.78 [†]	0.60 [†]
TAT, kg	0.43 [†]	0.32	0.57 [†]	0.37 [*]
Waist (L ₄ -L ₅) vs.				
Age, yr	0.40 [*]	0.01	0.13	0.08
Body weight, kg	0.11	0.21	0.29	0.30
Height, m	0.03	0.32	0.11	-0.25
IMAT, kg	0.61 [†]	0.44 [*]	0.39 [†]	0.52 [†]
TAT, kg	0.26	0.16	0.31 [*]	0.37 [*]
Shoulders vs.				
Age, yr	-0.22	0.35	-0.03	-0.11
Body weight, kg	0.40 [*]	0.25	0.04	-0.09
Height, m	0.23	0.21	0.04	-0.23
IMAT, kg	0.44 [†]	0.21	0.37 [*]	0.35 [*]
TAT, kg	0.43 [†]	0.29	0.04	0.12
Upper arm vs.				
Age, yr	0.09	-0.07	0.10	0.14
Body weight, kg	0.19	0.56 [†]	0.48 [†]	0.51 [†]
Height, m	-0.09	0.27	-0.11	-0.36 [*]
IMAT, kg	0.49 [†]	0.62 [†]	0.61 [†]	0.77 [†]
TAT, kg	0.25	0.57 [†]	0.46 [†]	0.58 [†]

	Women			Men
	African-American	Asian	Caucasian	Caucasian
Forearm vs.				
Age, yr	0.13	0.19	−0.02	0.23
Body weight, kg	0.42 [‡]	0.58 [‡]	0.56 [‡]	0.45 [‡]
Height, m	−0.08	0.57 [‡]	0.05	−0.13
IMAT, kg	0.67 [‡]	0.68 [‡]	0.61 [‡]	0.64 [‡]
TAT, kg	0.50 [‡]	0.44 [*]	0.58 [‡]	0.56 [‡]

N, no. of subjects. IMAT, intermuscular adipose tissue; TAT, total adipose tissue.

* Correlation is significant at the 0.05 level (2-tailed);

[‡] correlation is significant at the 0.01 level (2-tailed).

Table 3
Regression coefficients for the relationship of single and multiple IMAT slices to total body IMAT

	Regression Coefficients						Validation SEE
	Midcalf	Midthigh	Buttocks	Waist (L ₄ -L ₅)	Upper Arm	Intercept	
Women							
African-American							
One variable		10.4 [‡]				0.5 [‡]	0.36
Two variables		8.3 [‡]	8.3 [†]			0.4 [‡]	0.31
Three variables	14.1 [†]	6.7 [‡]	7.2 [†]			0.4 [‡]	0.28
Asian							
One variable	160.2 [‡]					0.7 [‡]	0.27
§		11.4 [†]				0.4 [†]	0.32
Two variable	141.9 [‡]	9.1 [†]				0.4 [†]	0.21
Three variable	133.3 [‡]	8.6 [†]		7.1 [†]		0.3 [†]	0.18
Caucasian							
One variable		15.5 [‡]				0.4 [‡]	0.29
Two variables		11.0 [‡]	7.0 [‡]			0.2 [†]	0.23
Three variables		8.0 [‡]	7.8 [‡]		21.3 [*]	0.2 [†]	0.21
Men							
Caucasian							
One variable		13.8 [‡]				0.3 [‡]	0.21
Two variables	22.0 [†]	12.2 [‡]				0.2 [‡]	0.18
Three variables	21.9 [‡]	11.0 [‡]		10.6 [‡]		0.2 [‡]	0.15

Dependent variable is IMAT.

* $P < 0.05$,

† $P < 0.01$,

‡ $P < 0.001$. Adjusted R^2 , adjusted explained variance, SEE, standard error of estimate; Validation SEE, SEE from the deleted residuals validation.

§ If midthigh slice is forced into the regression model first for consistency with other three groups, these are the values of coefficients.