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ORIGINAL ARTICLE

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Abstract

Objectives. 1) Examine associations between visceral adipose tissue (VAT), subcutaneous abdominal adipose tissue (SAAT), and anthropometric and demographic variables; 2) generate and cross-validate prediction equations for estimating VAT and SAAT in overweight Latino children. *Study design.* Cross-sectional. *Participants.* 196 overweight 8–13-year-old Latino youth. Two-thirds (n = 131) were randomly assigned to a development group to generate prediction equations for VAT and SAAT; one-third (n = 65) was used as a cross-validation group. *Methods and procedures.* Anthropometric measurements (height, weight, skinfold thicknesses, and circumferences) were performed. VAT and SAAT were measured using magnetic resonance imaging (MRI). *Results.* The strongest univariate correlate for VAT was waist circumference (WC) ($r = 0.65$, $p < 0.01$) while the strongest correlate for SAAT was hip circumference ($r = 0.88$, $p < 0.001$). Regression analyses showed ∼50% of the variance in VAT was explained by WC (43.8%), Tanner stage (4.2%) and calf skinfold (1.7%). Variance in the SAAT model was explained by WC (77.8%), triceps skinfold (4.2%) and gender (2.3%). Residual analyses showed no bias in either equation. Though mean differences between measured and predicted VAT and SAAT were small, there was a large degree of variability at the individual level especially for VAT. *Conclusions.* Both VAT and SAAT prediction equations performed well at the group level, but the relatively high degree of variability suggests limited clinical utility of the VAT equation. MRI is currently required to derive an accurate measure of VAT at the individual level.

Key words: *Overweight, anthropometry, Hispanic, child, magnetic resonance imaging*

Introduction

It is well established that total body fat, and central fat distribution in particular, are related to an adverse metabolic profile. Previous reports have revealed that visceral adipose tissue (VAT) in children is positively associated with diastolic blood pressure (1), triacylglycerol (2), markers of systemic inflammation (3) and inversely related to HDL cholesterol (2) and insulin sensitivity (4,5). In addition, evidence suggests that increased subcutaneous abdominal adipose tissue (SAAT) is also associated with metabolic risk factors (6–8). In a previous study of overweight Latino children that included measures of VAT and SAAT (using MRI) and total body fat mass (using dual-energy X-ray absorptiometry, DXA), we previously showed an independent and inverse relationship of these adi-pose measures with insulin sensitivity; however, the relationship between insulin sensitivity and VAT was strongest (4). The specific accumulation of visceral fat may at least partly explain the increased risk of type 2 diabetes in young Latinos. From a clinical standpoint, the measurement of abdominal fat distribution may be important in this high-risk population in the treatment and prevention of type 2 diabetes.

Although our research group (4, 9,10) and others (2, 11,12) have measured VAT and SAAT using MRI and computed tomography (CT) in children, the limited availability, high cost, and radiation exposure (for CT) have restricted the widespread application of these methods beyond the clinical research setting. Consequently, it is important to investigate alternative, indirect means for predicting VAT and SAAT in children. For instance, several investigators

have developed prediction equations for adults (13,14) and children (15,16) to estimate VAT and SAAT using anthropometry, demography and other body composition variables. Developing and validating equations for predicting VAT and SAAT using simple and practical variables can facilitate broader application of these equations. These equations would become relevant to epidemiological or community-based investigations in which imaging procedures are unavailable. To date, no published reports have established prediction equations for estimating VAT and SAAT in overweight Latino boys and girls. Thus, the objectives of this study were to 1) examine the associations between VAT, SAAT, and anthropometric and demographic variables and 2) develop and cross-validate prediction equations for estimating VAT and SAAT using anthropometric and demographic indicators.

Methods and procedures

Subjects

Analyses included 196 children (n = 113 boys and n = 83 girls) from the Los Angeles County area who are part of the University of Southern California Study Of Latino Adolescents at Risk for diabetes (SOLAR Diabetes Project), an ongoing longitudinal study examining behavioral and metabolic risk factors for type 2 diabetes. Data from this cohort have been published previously (4, 17–20). Study participants satisfied the following criteria for inclusion: age- and gender-specific body mass index (BMI) $\geq 85^{th}$ percentile (21); Latino background (all four grandparents were of Latino descent); 8–13 years of age; positive family history for type 2 diabetes (sibling, parent or grandparent) and absence of type 2 diabetes evaluated through an oral glucose tolerance test and established diagnostic criteria (22). These analyses included boys and girls (n = 196) selected from the larger population (n = 222) who had complete data for all variables. Some children did not have MRI performed because of scheduling conflicts, missed appointments by the children/families or other logistical issues. Children who did not have an MRI (26/222, 11.7%) did not differ in age, gender distribution, Tanner stage, WC or total body composition from those children who completed an MRI (196/222, 88.3%) (data not shown). Participants were not currently taking any medications nor previously diagnosed with any clinical condition known to influence body composition, insulin sensitivity, physical activity or dietary intake. Prior to the onset of testing, informed consent and assent were obtained from parents and children, respectively. This investigation was

approved by the Institutional Review Board of the University of Southern California, Health Sciences Campus.

Protocol

Outpatient screening visit and anthropometry. Children arrived at the USC General Clinical Research Center at $\sim$0800 hours after an overnight fast. Physical maturation was assessed by a pediatrician according to the criteria of Marshall and Tanner (23,24). Clinical nursing staff measured height to the nearest 0.1 cm using a wall-mounted stadiometer and weight to the nearest 0.1 kg using a medical balance-beam scale; BMI was subsequently calculated to confirm overweight status. A trained technician measured circumferences (waist and hip) and determined skinfold thicknesses (triceps, axilla, chest, subscapular, suprailiac, abdominal, thigh and calf) using Lange skinfold calipers (Beta Technology, Santa Cruz, CA) following the procedures of Lohman (25).

Body fat distribution. Approximately one week after the outpatient visit, participants returned to the study centre at $\sim$1300 hours for an overnight visit. During this appointment, VAT and SAAT were determined at the LA County/USC Medical Center Imaging Center. Single-slice T1-weighted scans were taken at the umbilicus with participants in the supine position. Scans lasted $\sim$2 minutes and a General Electric 1.5 Signa LX-Echospeed device with a General Electric 1.5T magnet and body coil were used (Waukesha, WI). Field of view ranges were between 432–500 mm and the image matrix was 256×256. Slice thickness was 10 mm, repeat-time ranges were between 516–533 ms, and echo-time ranged from 17–20 ms. A manual delineation of the abdominal (within the abdominal wall muscles) and subcutaneous (between the skin and abdominal wall muscles) areas for VAT and SAAT, respectively, were outlined with a light pen on the computer screen by a radiation imaging technologist. Data were integrated automatically using imbedded software provided by the manufacturer and a single radiologist reviewed all images post-processing. Due to financial limitations, we were unable to perform repeated scans on individuals or assess VAT and SAAT volumes through serial scans. However, the coefficients of variation for VAT and SAAT from single scans performed at this imaging center are 2.3% and 0.9%, respectively (26). In addition, we reanalyzed VAT and SAAT in a random sample of our population (n = 18) to derive an estimate of repeatability. The correlations for VAT and SAAT for analyses 1 and 2 were high (VAT: r = 0.98,

p <0.001; SAAT: r=0.99, p <0.001) and paired t-tests revealed there were no significant differences between analysis 1 and 2 for either VAT (t=0.6, SD=0.75, p=0.5) or SAAT (t=1.4, SD=0.96, p=0.2).

Statistics. Consistent with previous analyses (27,28), two-thirds of the participants (n=131) were randomly assigned to the development group for the construction of the VAT and SAAT prediction equations while the remaining one-third (n=65) was used as a cross-validation group. Differences between the development and cross-validation groups in anthropometry and demography were compared using the independent samples t-test (for continuous variables) and Chi-squared tests (for categorical variables). Pair-wise associations between VAT and SAAT and anthropometric and demographic predictor variables were examined using Spearman correlations. Anthropometric and demographic variables from the development group (n=131) were included in stepwise linear regression models to predict VAT and SAAT individually (the dependent variables). Parsimonious models were developed for both VAT and SAAT and assumptions of regression modeling were tested (e.g. collinearity, homoscedasticity, independence and normality). For a variable to be retained in the final model, a p-value <0.05 was used as the inclusion cut-off. Paired-sample t-tests were used to compare measured and predicted VAT and SAAT levels in the cross-validation group (n=65); measured and predicted VAT and SAAT values were in agreement if the difference was not significantly different from 0. Prediction equations were considered to cross-validate if the regressions between measured and predicted VAT and SAAT in the cross-validation group were not significantly different from the line of identity. Tests of residual against predicted VAT and SAAT values were conducted to examine bias in the prediction equations. Consistent with previous analyses (29), composite variables (e.g. BMI) were not included as potential independent predictors in the regression models. Exploratory analyses that included composite variables did not yield higher r^2 or lower SEE values compared to analyses that excluded these variables (data not shown). Statistical procedures were performed using SPSS for Windows version 11.0 (SPSS, Chicago, IL).

Results

As shown in Table I, there were no significant differences between the development group (n=131) and the cross-validation group (n=65) for

Table I. Comparison of the development group (n=131) and cross-validation group (n=65) according to demographic, anthropometric and body fat distribution.

	Development Group (n=131)	Cross-validation Group (n=65)
Boys/girls (n)	73/58	40/25
Age (yr)	11.6±1.7 (11.8)	11.7±1.6 (12.0)
Tanner stage (n)	I: 34 II: 47 III: 12 IV: 24 V: 14	I: 17 II: 17 III: 5 IV: 18 V: 8
Height (cm)	151.7±10.9 (152.8)	153.0±10.4 (152.6)
Weight (kg)	68.3±19.8 (63.3)	68.2±17.4 (64.4)
Waist circumference (cm)	89.5±13.1 (89.0)	88.5±12.6 (89.5)
Hip circumference (cm)	100.9±24.1 (95.5)	97.5±10.5 (96.0)
Triceps skinfold (mm)	21.5±8.0 (21.0)	21.4±7.1 (21.0)
Subscapular skinfold (mm)	25.0±8.8 (25.0)	23.4±7.6 (22.0)
Chest skinfold (mm)	13.7±6.6 (12.0)	13.2±6.1 (12.0)
Axilla skinfold (mm)	24.5±7.5 (25.0)	24.1±7.9 (24.0)
Abdominal skinfold (mm)	30.2±8.9 (30.0)	30.8±9.3 (31.0)
Suprailiac skinfold (mm)	25.2±8.4 (24.0)	24.6±8.2 (25.0)
Thigh skinfold (mm)	23.1±8.5 (22.0)	22.3±7.1 (22.0)
Calf skinfold (mm)	20.4±8.4 (20.0)	20.1±6.7 (20.0)
Visceral adipose tissue (cm^2)	48.9±22.0 (45.5)	43.8±22.0 (40.3)
Subcutaneous abdominal adipose tissue (cm^2)	356.4±140.0 (339.3)	344.1±128.6 (332.2)

No significant differences between groups were noted for any of the above variables. Data are presented as mean±standard deviation (median) except for the sample distribution by gender and Tanner stage.

any of the anthropometric or demographic variables. Correlation analyses revealed that WC (r=0.65, p <0.001) was the strongest correlate of VAT while hip circumference (r=0.88, p <0.001) was the strongest correlate of SAAT (Table II). Significant correlations for VAT ranged from 0.26–0.65, and for SAAT, correlations ranged from 0.24–0.93 (all p <0.001).

Development of prediction equations for VAT and SAAT

For VAT, stepwise linear regression revealed that WC (43.8%, p <0.001), Tanner stage (4.2%, p=0.002) and calf skinfold thickness (1.7%, p=0.04) were all retained in the prediction model (Table III; final model: 49.7%, p <0.001). Thigh skinfold thickness was initially retained as well; however, due to its collinearity with calf skinfold thickness, it

Table II. Spearman correlations between demographic and anthropometric variables and visceral adipose tissue (VAT) and subcutaneous abdominal adipose tissue (SAAT) determined using magnetic resonance imaging for the entire sample (n = 196).

	VAT	SAAT
Waist circumference (cm)	0.65*	0.87*
Abdominal skinfold (mm)	0.54*	0.74*
Suprailiac skinfold (mm)	0.47*	0.75*
Subscapular skinfold (mm)	0.47*	0.74*
Hip circumference (cm)	0.44*	0.88*
Weight (kg)	0.42*	0.83*
Axilla skinfold (mm)	0.41*	0.63*
Chest skinfold (mm)	0.30*	0.43*
Triceps skinfold (mm)	0.27*	0.61*
Thigh skinfold (mm)	0.26*	0.58*
Height (cm)	0.12	0.47*
Calf skinfold (mm)	0.08	0.45*
Age (yr)	0.02	0.37*
Tanner stage	−0.08	0.24*

*p-value <0.001; unmarked correlations were non-significant.

was removed, with little effect on the overall variance explained. For SAAT, stepwise linear regression showed that WC (77.8%, p <0.001), triceps skinfold thickness (4.2%, p <0.001) and gender (2.3%, p <0.001) were all significant predictors in the model (Table IV; final model: 84.4%, p <0.001). Weight, height, and WC were entered into separate models due to the strong collinearity; the model with WC was the most parsimonious and free of regression violations.

Cross-validation of prediction equation for VAT

In the cross-validation group, paired t-tests showed predicted VAT was not significantly different from measured VAT (mean difference ± standard deviation = −3.0 ± 16.5 cm^2, p = 0.2). Regressing residual VAT on predicted VAT indicated that there was no bias in the VAT prediction equation (Beta = −0.14; SE = 0.12; p = 0.3).

Cross-validation of prediction equation for SAAT

In the cross-validation group, paired t-tests showed predicted SAAT was not significantly different from measured SAAT (mean difference ± standard deviation = −1.0 ± 48.4 cm^2; p = 0.8). Regressing residual SAAT on predicted SAAT suggested that there was no bias in the SAAT prediction equation (Beta = 0.006; SE = 0.05; p = 0.9).

Discussion

We sought to identify anthropometric and demographic correlates of VAT and SAAT and to develop and cross-validate equations for predicting VAT and SAAT in overweight Latino children. We found that WC was the strongest correlate of VAT while hip circumference was most strongly associated with SAAT. Prediction equations that included anthropometric and demographic variables were able to explain ~50% and 84% of the variance in VAT and SAAT, respectively. WC accounted for the majority of the variance in VAT (~44%) and SAAT (~78%). The group means for measured and predicted VAT and SAAT did not differ between the development and cross-validation groups. Regression analyses comparing measured and predicted VAT and SAAT revealed good agreement and no bias between predicted and measured values.

Correlates of VAT and SAAT

Previous studies of children and adults have reported positive and significant correlations between anthropometric measures of adiposity (i.e. upper and lower body skinfold thicknesses, girth measurements, sagital diameter and BMI) and abdominal fat measured using MRI or CT (13–16, 30,31). In virtually all cases, reported relationships between proxy measures and directly imaged abdominal fat depots have been moderate-to-high (r ≥ 0.40) and, similar to the present study, tended to be more strongly associated with SAAT than VAT. It is difficult to

Table III. Forward-backward stepwise linear regression of the demographic and anthropometric predictors of visceral adipose tissue (VAT) measured using magnetic resonance imaging in the development group (n = 131).

Dependent Variable = VAT (cm^2)

Variable	Regression Equation	R^2; SEE (cm^2)
1. Waist Circumference (WC) (cm)	$(1.11 \times WC) - 50.62$	0.438; 16.6
2. Tanner stage (0 = prepubescent to 4 = adult)	$(1.2 \times WC) - (3.48 \times Tanner\ stage) - 53.21$	0.480; 16.0
3. Calf Skinfold (CSF) (mm)	$(1.27 \times WC) - (3.47 \times Tanner\ stage) - (0.36 \times CSF) - 52.37$	0.497; 15.8

Variables entered but not retained in the final model included: Gender, age, height, weight, hip circumference, abdominal skinfold, axilla skinfold, chest skinfold, subscapular skinfold, suprailiac skinfold, thigh skinfold and triceps skinfold. Model shown was the most parsimonious; free of collinearity and homoscedasticity violations.

Table IV. Forward-backward stepwise linear regression of the demographic and anthropometric predictors of subcutaneous abdominal adipose tissue (SAAT) measured using magnetic resonance imaging in the development group (n =131).

Dependent Variable = SAAT (cm^2)

Variable	Regression Equation	R^2; SEE (cm^2)
1. Waist Circumference (WC) (cm)	$(9.43 \times WC) - 487.87$	0.778; 66.2
2. Triceps Skinfold (TSF) (mm)	$(8.25 \times WC) + (4.09 \times TSF) - 470.18$	0.821; 59.8
3. Gender (boy = 0, girl = 1)	$(8.48 \times WC) + (3.73 \times TSF) + (43.23 \times Gender) - 501.93$	0.844; 56.0

Variables entered but not retained in the final model included: Tanner stage, age, height, weight, hip circumference, abdominal skinfold, axilla skinfold, calf skinfold, chest skinfold, subscapular skinfold, suprailiac skinfold and thigh skinfold. Model shown was the most parsimonious; free of collinearity and homoscedasticity violations.

identify unique and independent predictors of VAT because the independent variables included in the regression models tend to be highly correlated with both SAAT and VAT. Anthropometric variables likely correlate better with SAAT than VAT as skinfolds measure subcutaneous fat directly and SAAT is more reflective of total body fat. Data from the current study support this latter point; in our sample, we observed that total body fat mass from DXA was more strongly associated with SAAT than VAT (data not shown).

Predicting abdominal fat in youth

Several reports have been published whereby proxy measures were used to estimate VAT and SAAT. However, few studies have involved children exclusively. Although data regarding the prediction of SAAT were not included and cross-validation procedures were not reported, Owens et al. (16) were able to explain 63% of the variance in VAT. These data were produced with a model that included sagital diameter (40%), ethnicity (16%) and waist-to-hip ratio (7%) as independent predictors in a sample of obese Caucasian and African-American youth (n = 76; 7–16 years old). Fox and colleagues (32) constructed regression models that explained 41% and 69% of the variability in VAT and SAAT, respectively, in 11-year-old British boys and girls (n = 50). Variance in VAT was explained by waist circumference and subscapular skinfold whereas the subscapular-to-triceps skinfold (a measure of trunk-to-limb fatness) was the only measure retained in the model for SAAT. In a follow-up study in which 84% of the original sample was reassessed (11), Fox et al. explained 48% (for boys) and 41% (for girls) of the variance in VAT with abdominal skinfold (for boys) and subscapular skinfold (for girls) as the only measures retained in the two models; their ability to predict SAAT was not reported. Finally, Goran et al. (15) measured VAT and SAAT using CT in pre-pubertal obese and non-obese Caucasian and African-American children (n = 113) and predicted abdominal fatness using demographic, anthropo-

metric and DEXA-derived variables. Their equations predicted abdominal fat depots to a higher degree than the current study and this difference was more evident for VAT (r^2 = 0.82–0.85) than SAAT (r^2 = 0.92–0.96). The differences in predicting VAT and SAAT between the current study and that of Goran and colleagues (15) may be due to several factors including ethnic differences in abdominal fat patterning (Latinos vs. Caucasians + African Americans), study population (exclusively overweight vs. obese + non-obese), maturational stage (Tanner stage I through V vs. Tanner I only) and the slightly greater intra-sample variability in VAt and SAAT in our population. When considered in combination with the present study, research to date demonstrates collectively that there are differences in the best predictors of VAT that may be specific to the study population or methodologies.

Assessment of bias and utility of prediction equations

We employed several procedures to determine whether the prediction equations accurately predicted VAT and SAAT in our sample. Paired-sample t-tests and tests of identify showed that there was no overall mean difference between predicted and measured VAT and SAAT at the group level. In addition, residual analyses revealed a similar picture and demonstrated no bias in our models. Nevertheless, our data do not support the use of WC as a good proxy measure of VAT at the individual level as it explains only half of the variance, but the prediction equation may be useful for large population-based or epidemiological studies in which group estimates are needed. Our data provide stronger support for the prediction of SAAT suggesting that the prediction equation should perform reasonably well at both the individual and group levels.

Study limitations

Our investigation included only Latino children with a BMI ≥ 85th percentile. Although all children in

this study had a relatively high level of body fat (group mean: 38.4% body fat; range: 18.0–52.3%), there was a wide range of VAT (2.4–146.2 cm^2) and SAAT (77.4–787.5 cm^2). Given the health risks related to increased VAT and SAAT, the development of prediction equations would be most important for young Latinos with a high level of adiposity. It is presently unknown whether these prediction equations have the precision to accurately estimate changes in fat patterning associated with maturation or diet/exercise interventions at the group level, so applying these equations in a longitudinal study design is of interest. Other studies have suggested that sagittal diameter is the strongest correlate of VAT (16), so it remains to be determined whether the inclusion of this variable would have improved our ability to explain variance in VAT. The present study, and several others (14, 16, 33–35), have based the prediction of abdominal fat on single-slice images at the umbilicus, L4, or L4–L5 region. Given that VAT and SAAT single-slice estimates may depend on the site of measurement (36,37), future investigations should examine the prediction of VAT and SAAT derived using a sequence of abdominal images. In this respect, VAT and SAAT adipose tissue mass or volume could be estimated. Along with simple descriptive comparisons, we were interested in how well other prediction equations performed in predicting VAT and SAAT in our sample. Unfortunately, we were unable to test these existing equations as imaging procedures were discordant (15), not all equations were published (11) and anthropometric variables included in the earlier prediction equations were not assessed in the current study (16). Therefore, further cross-validation of our equations to predict VAT and SAAT in relation to pre-existing equations derived from other populations remains to be determined. Finally, the generalizability of these findings may be debated given the high health risk profile (e.g. overweight, Latino, positive family history of type 2 diabetes) of the sample population. Despite the wide range of VAT and SAAT levels observed within this sample, the influence of a positive family history of type 2 diabetes may confer a unique influence on body fat patterning. However, the high prevalence of overweight (38) coupled with an increasing population (39) suggest these data are relevant to an increasing number of children of Latino descent.

In summary, our findings indicate that WC is significantly correlated with abdominal fatness and explains a significant proportion of the variance for both VAT and SAAT in overweight Latino children. Based on our analyses, the utility of the VAT and SAAT prediction equations may be best applied at the group level. While the SAAT equation may also be useful at the individual level, sophisticated imaging procedures such as MRI are currently required to derive an accurate estimate of VAT in this population.

Acknowledgements

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