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Abstract

Objective: Given the importance of body fat distribution in chronic disease development, feasible methods to assess body fat are essential. This study compared dual-energy x-ray absorptiometry (DXA) in measuring visceral and subcutaneous adipose tissue (VAT and SAT) with magnetic resonance imaging (MRI).

Methods: VAT and SAT were assessed using similar DXA and MRI protocols among 1,795 elderly participants of the Adiposity Phenotype Study (APS) and 309 children/adolescents in Shape Up! Kids (SKids). Spearman correlations, Bland–Altman plots, and coefficients of determination (R^2) assessed agreement between DXA and MRI measures.

Results: DXA overestimated SAT values in APS (315 vs. 229 cm^2) and SKids (212 vs. 161 cm^2), whereas DXA underestimated VAT measures (141 vs. 167 cm^2) in adults only. The correlations between DXA and MRI values were stronger for SAT than VAT (APS: $r = 0.92$ vs. 0.88; SKids: 0.90 vs. 0.74). Bland–Altman plots confirmed better agreement for SAT than VAT despite differences by sex, ethnicity, and weight status with respective R^2 values for SAT and VAT of 0.88 and 0.84 (APS) and 0.81 and 0.69 (SKids).

Conclusion: These findings indicate that SAT by DXA reflects MRI measures in children and older adults, whereas agreement for VAT is weaker for individuals with low VAT levels.

INTRODUCTION

Excess body weight is a strong predictor of health status and chronic diseases, but body fat distribution, i.e., the amount of visceral adipose tissue (VAT) versus subcutaneous adipose

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CONFLICT OF INTEREST
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tissue (SAT), also plays a major role (1). VAT, the more metabolically active fat component, is an important predictor for mortality (2) and chronic conditions, such as diabetes (3) and cardiovascular disease (4). Measuring VAT requires imaging technology, ideally computed tomography (CT) or magnetic resonance imaging (MRI) (5). MRI is considered the gold standard, but participant burden and costs make it challenging to perform assessments in larger study populations, whereas dual-energy x-ray absorptiometry (DXA) assessment is more commonly available. However, it is not known how well MRI-based VAT can be predicted from DXA-based measurements across the life-span, ethnic groups, and individuals with a wide range of BMI. Among published comparisons of VAT measured by DXA and MRI (6-9), all correlations were very strong and highly significant ($r > 0.90$). Of these reports, only one reported on African American and Hispanic participants (7) and one on Middle Eastern participants (8). A few studies among young populations compared VAT assessed by DXA with MRI. In a study among young girls, DXA measures were strongly correlated with MRI values (10). As part of a lifestyle intervention, the accuracy of DXA-derived VAT was compared with MRI among 61 children with normal weight and obesity (11). DXA- and MRI-VAT outcomes were strongly associated ($r = 0.90$, $p < 0.001$) at baseline. A report based on 330 adolescents aged 10 to 16 years from different ethnic backgrounds also reported significant correlations ($r = 0.78$, $p < 0.001$) between DXA and MRI values (12). In addition, two reports in younger populations obtained weaker correlations between body fat measures obtained by DXA and MRI, because L1-L4 regional fat mass ($r = 0.71$) and truncal fat mass ($r = 0.44$), and not specifically VAT content, were assessed (13,14). The current analysis tested the hypothesis that DXA-based SAT and VAT measures (as compared with MRI) provide valid information in research studies among populations of different age, ancestry, and BMI with the goal to report correlations for a wide range of individuals with different characteristics using a similar study approach. In a cross-sectional design, data collected from the Adiposity Phenotype Study (APS) (15) within the Multiethnic Cohort (MEC) and from the Shape Up! Kids Study (Skids) (16) were analyzed to address the following questions: What is the relation of VAT measured by MRI and DXA in children (16) and older adults (17) from five different ethnic groups and a wide range of BMI? Is DXA equally predictive of VAT and SAT assessed by MRI across categories of age, sex, ethnicity, and BMI status? How much variability in MRI-based measures of VAT and SAT do the respective DXA measures explain, after including relevant covariates?

METHODS

APS

Study participants (17) were recruited from the MEC, an ongoing prospective study in Hawaii and Los Angeles, California, of diet, lifestyle, and genetic risk factors for cancer and other chronic diseases with more than 215,000 men and women aged 45 to 75 years at recruitment of mainly Japanese American, Native Hawaiian, White, African American, and Latino ancestry. All cohort members completed a 26-page questionnaire by mail in 1993 to 1996 (5). As described previously (15), APS targeted a subset of MEC members who were 60 to 72 years of age as of January 2013 and living in the catchment area of the study clinics. Mailed invitations were followed by screening telephone calls to exclude individuals

with the following characteristics: current reported BMI outside the target range (18.5 to 40 kg/m^2), current or recent (<2 years) smoking, soft or metal implants (other than knee or hip replacement) or amputations, claustrophobia, insulin treatment, thyroid medication, or other serious health conditions.

During 2013 to 2016, recruitment was conducted within 60 sex/ethnicity/BMI strata to balance the composition of the study population. Eligible cohort members visited clinics to complete anthropometric and DXA and MRI imaging using the same protocol, fasting blood sample collection, and questionnaires. All participants completed a survey that included a quantitative food frequency questionnaire, as well as questions on demographics, medical conditions, anthropometric measures, physical activity, and other lifestyle factors (15). Institutional Review Boards at University of Hawaii (CHS#17200) and University of Southern California (#HS-12-00623) approved the protocol; all participants signed informed consent forms.

Shape Up! Kids

This ongoing investigation has the goal to recruit 720 children aged 5 to 17 years (16). The current analysis is based on the first half because recruitment had stopped because of the pandemic, and the sample size appeared sufficient in size across strata to examine the underlying relation. To obtain a diverse study population, enrollment was stratified by age, ethnicity, sex, BMI *z* score, and location (San Francisco, California; Baton Rouge, Louisiana; and Honolulu, Hawaii) using convenience sampling. Exclusion criteria included pregnancy, missing limbs, presence of significant nonremovable metal in the body, or a history of body-altering surgery. Questionnaires included an online version of the Health Behavior in School-Aged Children survey (18) and the Physical Activity Questionnaire for Older Children or Adolescents (19). Human participants approval was obtained from the Institutional Review Boards at the three locations: Pennington Biomedical Research Center (IRB study #2017-10, FWA #00006218), University of California, San Francisco (IRB #16-20197), and University of Hawaii Institutional Review Board (IRB #24282). Both parents, if appropriate and available, gave informed consent. Children aged 7 to 17 years provided written assent and those aged 5 to 6 years old gave verbal assent.

MRI imaging

For the participants in Hawaii, DXA and MRI assessments were performed on the same equipment; the other locations applied the identical study protocol. The same investigator (SDB) analyzed all MRI images, making the results highly comparable. In both studies (15,20), adipose tissue was measured at four intervertebral sections (L1–L2, L2–L3, L3–L4, and L4–L5). In adults (15), abdominal VAT/SAT was measured using an axial gradient-echo sequence with water suppression and breath-hold (25 sections, 10-mm thickness, 2.5-mm gap, repetition time [TR]/echo time [TE] = 140/2.6 milliseconds, 70° flip angle). Among children/adolescents (20), both measures were obtained from a whole-body 2-point Dixon acquisition (2.6-mm sections, 0-mm gap, TR = 3.77 milliseconds, TE = 1.23/2.46 milliseconds, flip angle = 5°, in-plane resolution 256×144). The main reason for the different methods is that data were combined from two different studies with distinct outcomes. APS aimed to examine liver fat and VAT/SAT measures in older adults (15)

and it was designed to keep the total scan time within 20 to 25 minutes. This procedure allowed the acquisition of scout images, two data sets in the liver (3-point measures) as well as one covering L1 and L2 through L4 and L5. The study in children/adolescents was designed to measure whole-body adipose tissue using the 2-point Dixon method (20). This made it possible to measure the entire body with one sequence repeated four to seven times at various locations. One advantage of the 3-point method is it allows for correction due to changes in T2* primarily due to iron deposition, which is more important in adults than in young people. A comparison between 2-point, 3-point, and spectroscopy showed strong correlations across methods (21), as did a comparative study (2-, 3-, and 6-point MRI) among young and older men (22).

MRI images corresponding to the four lumbar sections were selected from the T2-weighted sequence (APS) and the Dixon sequence fat images (SKids). In either case, thresholds were applied to the images before manually cleaning signal from spine, spine muscle, or chest wall muscle and binarizing the images, which were analyzed using Fiji (17). For each cross-sectional segment, the total adipose area (in cm^2) inside the dermis was determined. Next, VAT inside the abdominal muscle wall was traced manually and the VAT area (intra- and extraperitoneal fat) was determined. The first volume included SAT + VAT from the abdomen cross-sectional area. The second volume included only the VAT, whereas the SAT area was derived from the difference of the measures. As in previous APS reports, means for SAT and VAT values as assessed in the four sections (L1-L5) were computed for analysis (15,23).

DXA imaging

The total and regional body composition was determined by a whole-body DXA (Hologic Discovery A at University of Hawaii and University of Southern California) scan, which was calibrated using daily quality control phantoms. DXA, as represented by the Hologic systems, analyzes VAT and SAT in one special section, which is an automatically defined 5-cm-thick region placed above the iliac crest within the android region (24,25) roughly corresponding to the L4/L5 intervertebral section commonly used for MRI VAT scans. The software automatically locates the outer and inner lateral borders of the abdominal wall. The total fat mass in each pixel within the abdominal walls is determined using standard DXA methods. However, DXA systems cannot distinguish or segment the overlaying fat subcomponents of SAT and VAT mass. Thus, a geometric and densitometric model, that is part of the system's software, is used to subtract off the overlaying SAT mass from the total fat mass resulting in a VAT mass estimate (26). VAT mass is represented as a cross-sectional area (cm^2) by dividing by fat density and the thickness of the region. All DXA image files for both studies were centrally analyzed by two trained technicians, i.e., one for APS and one for SKids, on Hologic Apex version 5.6 with the National Health and Nutrition Examination Survey (NHANES) Body Composition Analysis calibration option disabled (27). Both readers were validated to a criterion reader using a training data set.

Biomarkers

In both studies, fasting blood samples were collected and a large selection of biomarkers was assessed. Given their known association with different body fat compartments, alanine

transaminase (ALT), homeostatic model assessment for insulin resistance (HOMA-IR), low-density lipoprotein (LDL), and high-density lipoprotein (HDL) were selected as correlates of VAT. HOMA-IR was calculated as (fasting insulin (mU/L) × fasting glucose (mg/dL))/405 (28). In APS, a Cobas Mira Plus Chemistry autoanalyzer was used to determine concentrations of total cholesterol, HDL, triglycerides (all kits from Pointe Scientific), and glucose (Randox Laboratories) (29). A serum-based enzyme-linked immunosorbent assay (ELISA) kit was used to measure insulin (EMD Millipore). In SKids, serum chemistry panels were assayed using a DXC600 instrument (Beckman Coulter, Inc.) (30). LDL cholesterol was calculated as [total cholesterol] − [HDL cholesterol] − [triglycerides/5] (all values in mg/dL). Insulin was measured by immunoassay on an Immulite 2000 platform (Siemens Corp.).

Statistical analysis

A common data set that included all shared variables (VAT and SAT measured by DXA and MRI, age, sex, ethnicity, BMI, biomarkers) for the two studies was created. All analyses were performed separately for each study. Descriptive statistical analyses were applied to compare the distribution of DXA- and MRI-based VAT and SAT measurements. Box and whisker plots for VAT and SAT by 3-year age groups were prepared (31). Spearman correlation coefficients were computed and plotted by sex and ethnic category separately for the two studies. To estimate possible predictors of MRI beyond DXA values, linear regression models with DXA as independent and MRI measures (both continuous variables) as dependent variables were performed; sex, ethnicity, BMI status, and age were included as covariates in the full model. In a final exploratory model, which aimed to adjust for metabolic parameters known to be associated with body fat, four biomarkers (ALT, LDL, HDL, and HOMA-IR) were added as independent variables. To evaluate differences in fit across models, coefficients of determination (R^2) were computed using general linear regression. Bland–Altman plots with MRI values on the x-axis and percent difference between MRI and DXA values on the y-axis were created to visualize the influence of sex, ethnicity, and BMI status on agreement separately for each study (31). To check for nonlinearity, restricted cubic splines using a standard method were applied (32). In this approach, nonzero estimates for spline basis functions other than the first one would indicate potential nonlinearity in the model.

RESULTS

The respective study populations for APS and SKids (Table 1) consisted of 1,795 and 309 participants from five ethnic groups with mean (SD) ages of 69.2 (2.7) and 12.3 (3.4) years. By design, the proportions of individuals with normal weight, overweight, and obesity were similar in APS, but in SKids, 60% of participants were normal weight. As expected, mean SAT and VAT levels were higher among adults than the young population; the respective MRI values were 229 (102) cm^2 and 167 (83) cm^2 in APS and 161 (141) cm^2 and 40 (29) cm^2 in SKids. Although the range of SAT values was similar for the two studies (102 to 751 cm^2 in APS and 141 to 805 cm^2 in SKids), the maximum values for VAT were much lower in the younger population (229 vs. 618 cm^2 in APS). As compared with MRI, the mean DXA SAT measures were higher in both studies (315 vs. 229 in APS and 212 vs.

161 cm^2 in SKids), with higher values in females than males. On the other hand, DXA VAT measures were lower (141 vs. 167 cm^2) than MRI VAT values in APS participants but not SKids (43 vs. 40 cm^2). Male participants in APS (but not in SKids) had higher VAT values than females.

Mean VAT and SAT values differed significantly by ethnic group (Table 2). The correlations between DXA- and MRI-derived measures were stronger for SAT than VAT. For SAT, the respective correlations were 0.92 in APS and 0.90 in SKids. Little difference in SAT correlations was seen across sex and ethnic groups, with ranges of 0.75 to 0.98 in both studies (Figure 1). However, for VAT, the respective correlation coefficients were substantially lower, with 0.88 in APS and 0.74 in SKids (both $p < 0.0001$). The weaker correlation for VAT than SAT was also reflected across sex-ethnic groups, in which the values ranged from 0.62 to 0.94, but the discrepancy was greater in SKids than APS. The correlations were weakest in Asian and Native Hawaiian/Other Pacific Islander males. As seen in Figure 2, both mean SAT and VAT increased with age, but SAT increased faster and reached adult levels by age 14 to 18 years. However, VAT was very low in SKids participants and at least fourfold greater in adults after age 60.

As indicated by their greater distance from the zero-bias line in the Bland–Altman plots (Figure 3), SAT values as measured by MRI were overestimated to a greater degree by DXA among females than males in both studies. For VAT in APS, DXA primarily underestimated the MRI values among men and not in women. In SKids with its limited range of MRI values, the agreement as shown by the long distance from the zero-bias line was modest for boys and girls. By ethnic group (Figure 4), clear differences were not visible, but by BMI status (Figure 5), the agreement between DXA and MRI was much better among individuals with overweight and obesity than normal weight individuals in both studies.

In models for SAT (Table 3), the slopes of 0.71 and 0.76 indicate that MRI values increased slower than DXA, whereas for VAT, MRI increased faster than DXA among adults (1.14) but slower among kids (0.64). The slope of <1 also indicates that the agreement was best near the mean but grew toward the end of the DXA range. With a slope of <1 and intercept of <0 among kids, DXA was consistently higher than MRI across the range, and the difference grew larger with larger amounts of fat.

The additional covariates explain 2% to 5% variability in the MRI measures and indicate that the importance of covariates differed by study. Although BMI explains an extra 2% variability among adults, age, sex, and biomarkers did not improve the fit. Among children, age and sex explain 3% variability and biomarkers explain another 1%, but BMI did little to improve the fit. Being female was associated with lower SAT and overweight/obesity status with higher SAT. Age was associated with higher SAT in children and adolescents only. By ethnicity, African American participants had higher and Asian participants had lower SAT than White participants in APS only. The respective R^2 values for SAT were 0.85 and 0.77 for APS and SKids without any covariates, and they increased to 0.86 and 0.81 with sex and age added and to 0.88 and 0.81 after including BMI status and ethnicity. Adding the four biomarkers did not improve the models to a substantial degree.

For VAT, the relation of DXA with MRI values was stronger in APS than SKids ($\beta = 1.14$ vs. 0.64). Age was associated with higher values in SKids and female sex with lower values in APS only. African American and Latino ancestry was associated with lower VAT values. For VAT, the basic models had R^2 values of 0.76 and 0.64, 0.82 and 0.65 after including sex and age, and 0.84 and 0.69 for the full models. Again, the addition of four biomarkers did not improve the prediction model.

Restricted cubic splines indicate that the first function in the spline basis was linear and that the other functions had estimates close to 0, indicating that there was very little nonlinearity present. Therefore, the linear form of the model was adequate.

DISCUSSION

SAT was overestimated by DXA in APS and SKids, whereas DXA underestimated VAT in adults but not children. In both studies, MRI values for SAT were overestimated to a greater degree among females than males and individuals with normal compared with excess body weight. In particular, agreement for VAT in children/adolescents and individuals with low BMI was smaller than for adults and persons with higher BMI. Mean levels of SAT and VAT increased by age in both study populations. In general, prediction of MRI from DXA measures was better for SAT than for VAT. A lower agreement between methods for VAT than SAT despite strong correlations was also reported by an analysis of UK Biobank participants (9). For VAT, DXA primarily underestimated the MRI values among men and normal weight APS participants, whereas no distinct patterns were detected in SKids.

Among nine previous reports in adults, five studies compared VAT by DXA with CT measures (24,33-36) and four with MRI measures (6-9). Of these, four used Hologic (7,24,34,36) and five GE (6,8,9,33,35) systems for DXA assessment. All correlations were strong and highly significant ($r > 0.90$). However, the agreement between methods varied considerably, with DXA estimating lower or higher VAT values than MRI or CT without a clear pattern, possibly because GE systems estimate total VAT, whereas Hologic assesses the area in the L4/L5 intervertebral space. Although four reports showed overestimation by DXA (8,33-35), in four studies, DXA underestimated CT/MRI values (6,9,24,36), as in the current investigation. A report in which DXA underestimated MRI by 30% (6) agrees with lower DXA VAT than MRI VAT values in APS (141 vs. 167 cm^2). In the Dallas Heart Study (DHS), DXA underestimated VAT at lower and overestimated at higher VAT levels (,7) consistently across race, BMI, and body fat strata.

The current finding of lower correlations among children than adults agrees with the three previous studies, which reported coefficients between 0.70 and 0.90 (10-12). In contrast to the small difference between DXA and MRI VAT values in SKids, DXA significantly overestimated VAT in two previous reports (10,11). However, significant proportional bias was observed, i.e., the difference between MRI-VAT and DXA-VAT estimations increased with higher volumes of VAT (10,11). In a study of 330 adolescents 10 to 16 years of age with diverse ethnic backgrounds (White, African American, and other race), mean VAT from DXA was significantly lower than VAT from MRI in the total study population and in all subgroups despite their strong correlation. As to other studies in young populations, an

MRI-based study in 5-year-old children showed that sex differences in body fat distribution become apparent at an early age (14). In a study with 10- to 11-year-old healthy children, DXA measures showed higher total body fat and lower VAT among girls than boys (37). A review described how girls tend to accumulate more SAT during and after puberty, depositing fat preferentially in the gynoid and extremity regions, whereas pubertal and postpubertal boys tend to deposit more fat in the abdominal region, particularly as VAT (38).

Looking at agreement by group indicates several differences. Although the results by sex tended to be similar, one study showed greater overestimates in men than women (8). Overall, sex differences in agreement between methods appear to be mostly the result of higher VAT levels in men than women (8,35,36). Similarly, the ethnic differences in the current analysis appear to be related to patterns of body fat distribution across groups (38). Among youths, VAT tends to be higher in White and Hispanic participants, whereas SAT is typically higher in African American youth. Asian youth typically have less gynoid fat but more VAT than White participants. The importance of overall adiposity for the accuracy between DXA and MRI values was confirmed repeatedly. Differences according to low and high VAT levels were seen frequently; agreement appears to be better at low than high levels in several reports (6,8,9,36) but at high levels in another report (34). The ethnic diversity in the current investigation adds a layer of complexity. As seen in Table 2, means for VAT estimated by DXA and MRI agree well for White and Native Hawaiian/Other Pacific Islander participants, whereas DXA overestimated VAT for African American, Latino, and Asian participants to different degrees. From the evidence among adults and the few studies among children/adolescents, it appears that agreement is largely driven by overall adiposity and relative distribution, which both depend on age, sex, and ancestry. The extremely low proportion of VAT among young children, in particular girls (Figure 2), definitely poses a challenge. Nevertheless, the strong correlations support the substitution of MRI by DXA imaging as long as researchers keep in mind these possible confounders.

To evaluate the agreement of DXA with MRI measures, one needs to consider the substantial discrepancies in methods. DXA estimates the lowest L4/L5 section, whereas in MRI, four slices throughout the abdomen are averaged. DXA estimates a cross-sectional area in one section from a planar mass-calibrated DXA image versus the direct measure of cross-sectional area from MRI and CT sections (39,40). The body regions and thickness of sections chosen for assessment and the separation technique to distinguish VAT from SAT also differ. Depending on the DXA make (GE vs. Hologic), the compartment location used for measurement by DXA may be smaller or larger than for MRI (6), e.g., GE DXA systems report VAT and SAT for the entire android region (33). As the specific fat measures in the current study are different from what many other studies define as regions of interest, both the absolute and the relative content of VAT are difficult to compare directly.

Strengths of the current report include the two age groups at both ends of the life-span using similar imaging techniques. To our knowledge, it is the first investigation to report VAT estimates in children and adolescents by MRI and DXA, providing new insights into accumulation of SAT and VAT early in life. The diversity of the study populations by ethnicity and BMI status provided a wide range of fat measures. One of the major limitations of this study is the lack of participants between 20 and 60 years to examine

development across the life-span. Also, the exclusion of participants with BMI > 40 kg/m^2 does not allow conclusions about the important group of individuals with class III severe obesity. Despite the similar imaging protocols, the different questionnaires in APS and SKids reduced the number of covariates that could be included into the models. A larger sample size for children and adolescents would have been desirable for further subgroup analyses. As only BMI and waist circumference have been established as measures for clinical decision-making, we cannot determine whether the different VAT estimates by DXA and MRI are clinically meaningful. Appropriate cut points would have to be established in larger investigations that assess disease end points.

The current findings indicate that DXA performs better at estimating SAT than VAT when compared with the gold standard of MRI, but correlations were above 0.7, which is generally considered strong. Future studies may choose DXA imaging instead of MRI to increase sample size and decrease participant burden while keeping in mind that DXA performance appears to be weaker in individuals with low levels of overall adiposity. Therefore, MRI may remain the superior approach for VAT assessment among individuals with a limited VAT range such as young or very low-weight populations. A certain amount of under- and overestimation despite strong correlation is a good reminder that correlations can be high in studies with a wide range even when the absolute values differ (9). To avoid the high cost of MRI (a minimum of $300 vs. $50 to $70 for DXA) and radiation from DXA (<10 μSv equivalent to 1 day at sea level), ultrasound methods currently under development may be used in the future. They would have the advantage of no radiation and low cost, but they can only indirectly measure VAT and SAT and, thus, have their own assumptions that may limit precision and accuracy (40).

In conclusion, this investigation was unique in examining two study populations with children/adolescents and elderly adults who underwent DXA and MRI imaging using similar protocols. Given the methodological differences in fat assessment between MRI and DXA, such as choice of landmarks and analyses methods, it is not realistic to expect DXA absolute measurements to fully agree with MRI values. On the other hand, the robust correlations of VAT and SAT estimates by both methods indicate that SAT assessment by DXA consistently reflects MRI measures across five ethnic groups in young and in elderly males and females. As both correlations and agreements between DXA and MRI measures for VAT were weaker and differed according to sex and BMI status as compared with SAT values, it may be necessary to image study participants with certain characteristics by CT or MRI, two methods that continue to be considered the gold standard for VAT assessment.

Funding information

REFERENCES

1. Tchernof A, Després JP. Pathophysiology of human visceral obesity: an update. Physiol Rev. 2013;93:359–404. [PubMed: 23303913]

2. Koster A, Murphy RA, Eiriksdottir G, et al. Fat distribution and mortality: the AGES-Reykjavik Study. Obesity (Silver Spring). 2015;23: 893–897. [PubMed: 25755182]

3. Xia M-F, Lin H-D, Chen L-Y, et al. Association of visceral adiposity and its longitudinal increase with the risk of diabetes in Chinese adults: a prospective cohort study. Diabetes Metab Res Rev. 2018;34:e3048. doi:10.1002/dmrr.3048 [PubMed: 30035847]

4. Lim S, Meigs JB. Links between ectopic fat and vascular disease in humans. Arterioscler Thromb Vasc Biol. 2014;34:1820–1826. [PubMed: 25035342]

5. Thomas EL, Fitzpatrick JA, Malik SJ, Taylor-Robinson SD, Bell JD. Whole body fat: content and distribution. Prog Nucl Magn Reson Spectrosc. 2013;73:56–80. [PubMed: 23962884]

6. Cheung AS, de Rooy C, Hoermann R, et al. Correlation of visceral adipose tissue measured by Lunar Prodigy dual X-ray absorptiometry with MRI and CT in older men. Int J Obes (Lond). 2016;40:1325–1328. [PubMed: 27003112]

7. Neeland IJ, Grundy SM, Li X, Adams-Huet B, Vega GL. Comparison of visceral fat mass measurement by dual-X-ray absorptiometry and magnetic resonance imaging in a multiethnic cohort: the Dallas Heart Study. Nutr Diabetes. 2016;6:e221. doi:10.1038/nutd.2016.28 [PubMed: 27428873]

8. Mohammad A, De Lucia Rolfe E, Sleigh A, et al. Validity of visceral adiposity estimates from DXA against MRI in Kuwaiti men and women. Nutr Diabetes. 2017;7:e238. doi:10.1038/nutd.2016.38 [PubMed: 28067890]

9. Borga M, West J, Bell JD, et al. Advanced body composition assessment: from body mass index to body composition profiling. J Investig Med. 2018;66:1–9. 10.1136/jim-2018-000722

10. Lee V, Blew R, Hetherington-Rauth M, et al. Estimation of visceral fat in 9- to 13-year-old girls using dual-energy X-ray absorptiometry (DXA) and anthropometry. Obes Sci Pract. 2018;4:437–447. [PubMed: 30338114]

11. Dias KA, Ramos JS, Wallen MP, et al. Accuracy of longitudinal assessment of visceral adipose tissue by dual-energy X-ray absorptiometry in children with obesity. J Obes. 2019;2019:2193723. doi:10.1155/2019/2193723 [PubMed: 31781386]

12. Kracht CL, Katzmarzyk PT, Staiano AE. Comparison of abdominal visceral adipose tissue measurements in adolescents between magnetic resonance imaging and dual-energy X-ray absorptiometry. Int J Obes (Lond). 2021;45:104–108. [PubMed: 32499526]

13. Laddu DR, Lee VR, Blew RM, Sato T, Lohman TG, Going SB. Predicting visceral adipose tissue by MRI using DXA and anthropometry in adolescents and young adults. Int J Body Compos Res. 2012;10:93–100. [PubMed: 26097436]

14. Karlsson A-K, Kullberg J, Stokland E, et al. Measurements of total and regional body composition in preschool children: a comparison of MRI, DXA, and anthropometric data. Obesity (Silver Spring). 2013;21:1018–1024. [PubMed: 23784906]

15. Lim U, Monroe KR, Buchthal S, et al. Propensity for intra-abdominal and hepatic adiposity varies among ethnic groups. Gastroenterology. 2019;156:966–975. [PubMed: 30445012]

16. Wong MC, Ng BK, Kennedy SF, et al. Children and adolescents' anthropometrics body composition from 3-D optical surface scans. Obesity (Silver Spring). 2019;27:1738–1749. [PubMed: 31689009]

17. Lim U, Ernst T, Buchthal SD, et al. Asian women have greater abdominal and visceral adiposity than Caucasian women with similar body mass index. Nutr Diabetes. 2011;1:e6. doi:10.1038/nutd.2011.2 [PubMed: 23449381]

18. Roberts C, Freeman J, Samdal O, et al. The Health Behaviour in School-aged Children (HBSC) study: methodological developments and current tensions. Int J Public Health. 2009;54:140–150. [PubMed: 19639259]

19. Crocker PR, Bailey DA, Faulkner RA, Kowalski KC, McGrath R. Measuring general levels of physical activity: preliminary evidence for the Physical Activity Questionnaire for Older Children. Med Sci Sports Exerc. 1997;29:1344–1349. [PubMed: 9346166]

20. Maskarinec G, Garber AK, Wong MC, et al. Predictors of liver fat among children and adolescents from five different ethnic groups. Obes Sci Pract. 2021;7:53–62. [PubMed: 33680492]

21. Kim H, Taksali SE, Dufour S, et al. Comparative MR study of hepatic fat quantification using single-voxel proton spectroscopy, two-point dixon and three-point IDEAL. Magn Reson Med. 2008;59:521–527. [PubMed: 18306404]

22. Grimm A, Meyer H, Nickel MD, et al. Evaluation of 2-point, 3-point, and 6-point Dixon magnetic resonance imaging with flexible echo timing for muscle fat quantification. Eur J Radiol. 2018;103:57–64. [PubMed: 29803386]

23. Maskarinec G, Namatame LA, Kang M, et al. Differences in the association of diet quality with body fat distribution between men and women. Eur J Clin Nutr. 2020;74:1434–1441. [PubMed: 31980746]

24. Micklesfield LK, Goedecke JH, Punyanitya M, Wilson KE, Kelly TL. Dual-energy X-ray performs as well as clinical computed tomography for the measurement of visceral fat. Obesity (Silver Spring). 2012;20:1109–1114. [PubMed: 22240726]

25. Shepherd JA, Sommer MJ, Fan BO, et al. Advanced analysis techniques improve infant bone and body composition measures by dual-energy X-ray absorptiometry. J Pediatr. 2017;181:248–253.e3. [PubMed: 27866821]

26. Pietrobelli A, Formica C, Wang Z, Heymsfield SB. Dual-energy X-ray absorptiometry body composition model: review of physical concepts. Am J Physiol. 1996;271(6 Pt 1):E941–E951. [PubMed: 8997211]

27. Shepherd JA, Ng BK, Sommer MJ, Heymsfield SB. Body composition by DXA. Bone. 2017;104:101–105. [PubMed: 28625918]

28. Kauffman RP, Baker VM, DiMarino P, Gimpel T, Castracane VD. Polycystic ovarian syndrome and insulin resistance in white and Mexican American women: a comparison of two distinct populations. Am J Obstet Gynecol. 2002;187:1362–1369. [PubMed: 12439532]

29. Morimoto Y, Conroy SM, Ollberding NJ, et al. Ethnic differences in serum adipokine and C-reactive protein levels: the multiethnic cohort. Int J Obes (Lond). 2014;38:1416–1422. [PubMed: 24522245]

30. Ng BK, Sommer MJ, Wong MC, et al. Detailed 3-dimensional body shape features predict body composition, blood metabolites, and functional strength: the Shape Up! studies. Am J Clin Nutr. 2019;110:1316–1326. [PubMed: 31553429]

31. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet. 1986;327:307–310.

32. Harrell FE Jr, Lee KL, Pollock BG. Regression models in clinical studies: determining relationships between predictors and response. J Natl Cancer Inst. 1988;80:1198–1202. [PubMed: 3047407]

33. Kaul S, Rothney MP, Peters DM, et al. Dual-energy X-ray absorptiometry for quantification of visceral fat. Obesity (Silver Spring). 2012;20:1313–1318. [PubMed: 22282048]

34. Bredella MA, Gill CM, Keating LK, et al. Assessment of abdominal fat compartments using DXA in premenopausal women from anorexia nervosa to morbid obesity. Obesity (Silver Spring). 2013;21:2458–2464. [PubMed: 23512706]

35. Lin H, Yan H, Rao S, et al. Quantification of visceral adipose tissue using lunar dual-energy X-ray absorptiometry in Asian Chinese. Obesity (Silver Spring). 2013;21:2112–2117. [PubMed: 23418061]

36. Fourman LT, Kileel EM, Hubbard J, et al. Comparison of visceral fat measurement by dual-energy X-ray absorptiometry to computed tomography in HIV and non-HIV. Nutr Diabetes. 2019;9:6. doi:10.1038/s41387-019-0073-1 [PubMed: 30804324]

37. Verduin WM, Van Den Helder R, Doodeman HJ, Struijf E, Houdijk AP. Dexa body composition assessment in 10–11 year healthy children PLoS One. 2016;11:e0165275. doi:10.1371/journal.pone.0165275 [PubMed: 27788168]

38. Staiano AE, Katzmarzyk PT. Ethnic and sex differences in body fat and visceral and subcutaneous adiposity in children and adolescents. Int J Obes (Lond). 2012;36:1261–1269. [PubMed: 22710928]

39. Hemke R, Buckless C, Torriani M. Quantitative imaging of body composition. Semin Musculoskelet Radiol. 2020;24:375–385. [PubMed: 32992366]

40. Simoni P, Guglielmi R, Aparisi Gómez MP. Imaging of body composition in children. Quant Imaging Med Surg. 2020;10:1661–1671. [PubMed: 32742959]

Study Importance

What is already known?

- Body fat distribution, i.e., the proportion of visceral (VAT) as compared with subcutaneous (SAT) adipose tissue, is an important predictor of chronic disease development.

- To measure VAT, magnetic resonance imaging (MRI) and computed tomography are considered the gold standard, but participant burden and costs make it challenging to perform assessments in larger study populations.

- Dual-energy x-ray absorptiometry (DXA) assessment is cheaper and more commonly available.

What does this study add?

- Given limited reports in young populations, this study presents new information about correlations and agreement between MRI and DXA imaging in children and adolescents.

- The findings show strong correlations between SAT by DXA and MRI across strata of sex, ethnicity, and weight status despite differences in absolute values of estimated SAT levels.

- As to VAT assessment by DXA, the correlations are moderate to strong, but differences in predicted values are greater among children/adolescents and individuals with low VAT levels.

How might your results change the direction of research or the focus of clinical practice?

- Future studies may choose DXA imaging instead of MRI to increase sample size and decrease participant burden, although correlations for VAT measures are not equally strong for all ethnic and weight groups.

- Pediatric investigations will carefully consider different imaging methods dependent on the age and body size of the younger study participants.
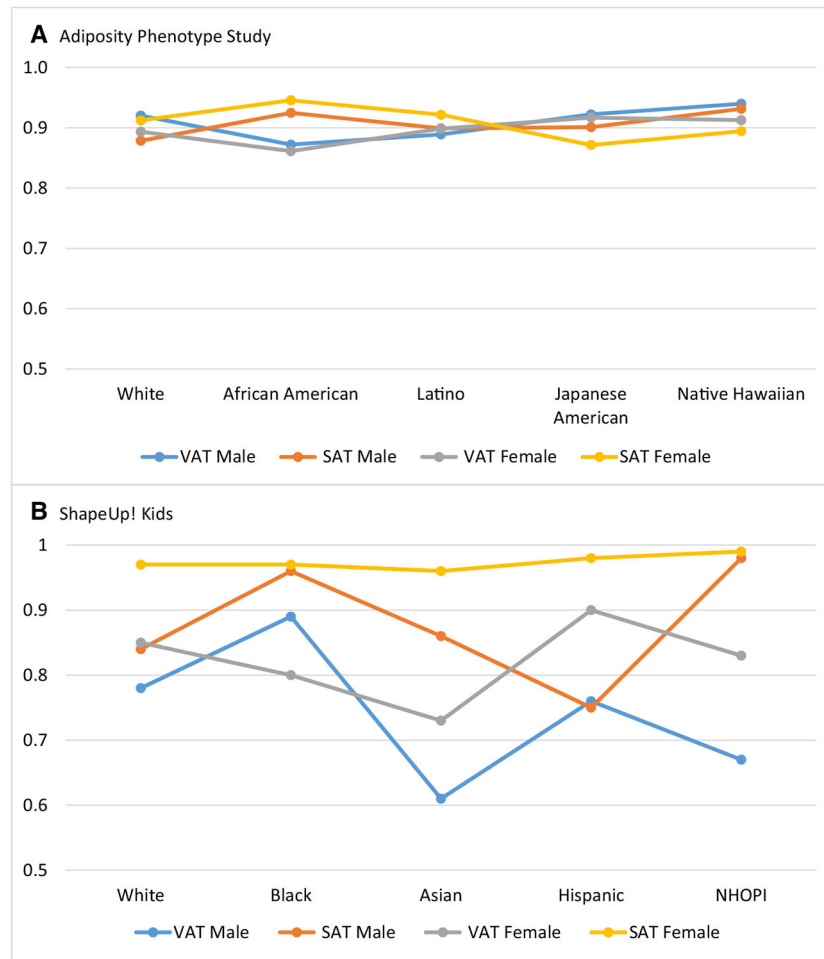
FIGURE 1.

Correlation of DXA- and MRI-based VAT and SAT measures by study and ethnic group. DXA, dual-energy x-ray absorptiometry; MRI, magnetic resonance imaging; SAT, subcutaneous adipose tissue; VAT, visceral and subcutaneous adipose tissue

FIGURE 2.
Mean VAT and SAT from MRI by 3-year age groups for APS and Shape Up! Kids. APS, Adiposity Phenotype Study; MRI, magnetic resonance imaging; SAT, subcutaneous adipose tissue; VAT, visceral and subcutaneous adipose tissue

FIGURE 3.

Bland–Altman plots of DXA- and MRI-based VAT and SAT measures by study and sex. APS, Adiposity Phenotype Study; SKids, Shape Up! Kids; DXA, dual-energy x-ray absorptiometry; MRI, magnetic resonance imaging; SAT, subcutaneous adipose tissue; VAT, visceral and subcutaneous adipose tissue
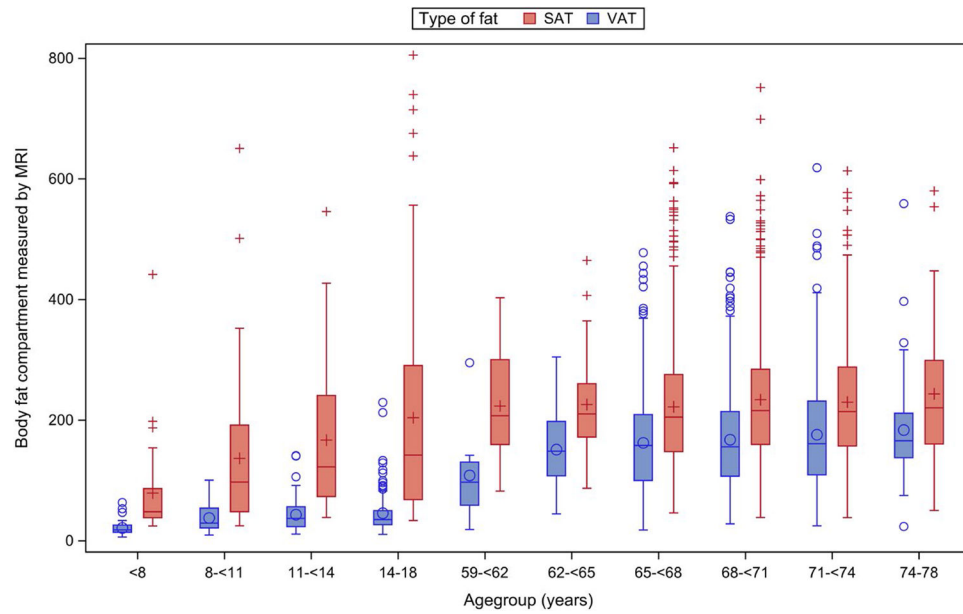
FIGURE 4.
Bland–Altman plots of DXA- and MRI-based VAT and SAT measures by study and ethnicity. APS, Adiposity Phenotype Study; DXA, dual-energy x-ray absorptiometry; MRI, magnetic resonance imaging; SAT, subcutaneous adipose tissue; SKids, Shape Up! Kids; VAT, visceral and subcutaneous adipose tissue
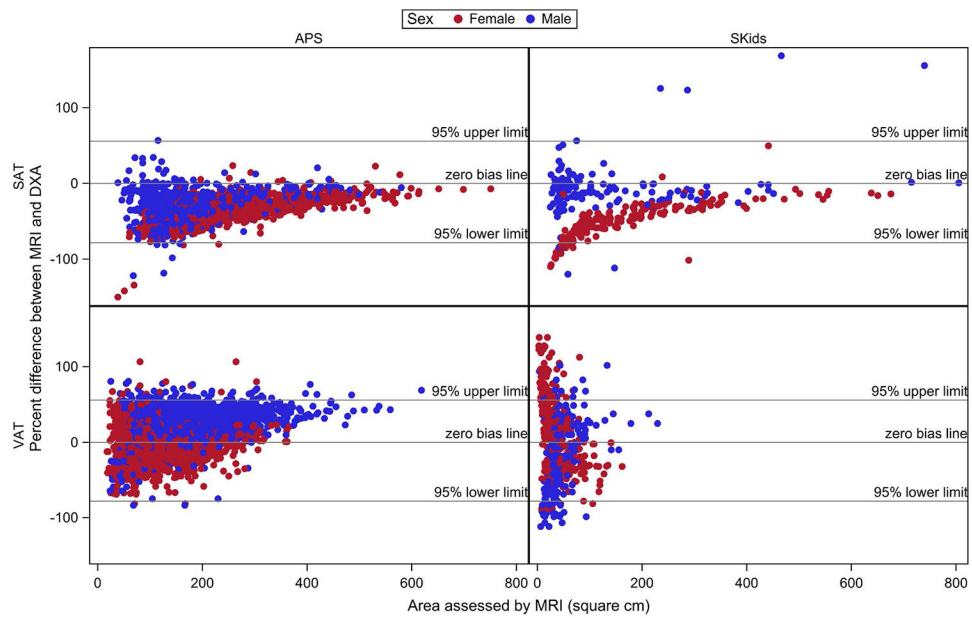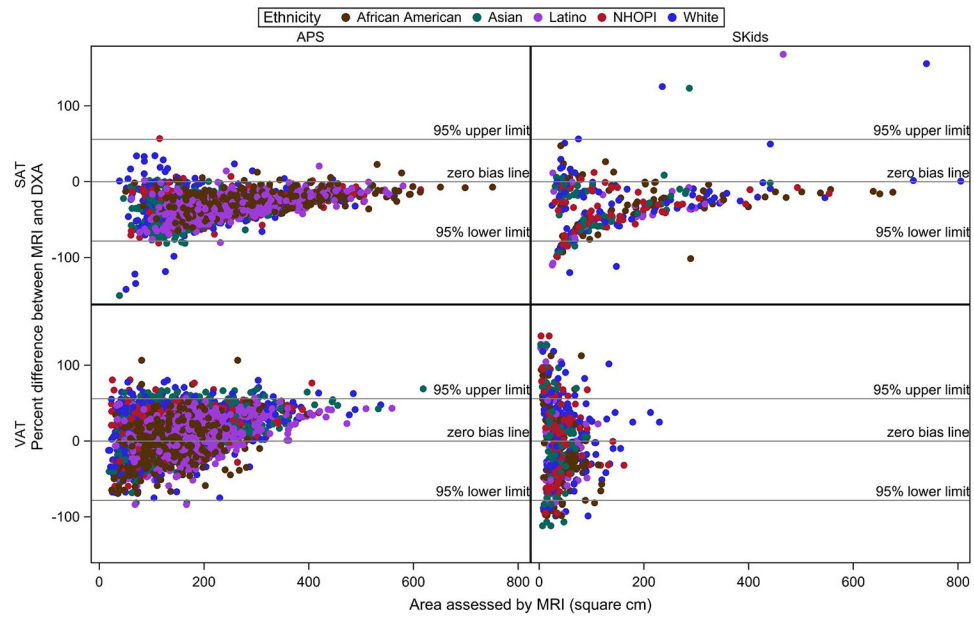
FIGURE 5.

Bland–Altman plots of DXA- and MRI-based VAT and SAT measures by study and BMI. APS, Adiposity Phenotype Study; DXA, dual-energy x-ray absorptiometry; MRI, magnetic resonance imaging; SAT, subcutaneous adipose tissue; SKids, Shape Up! Kids; VAT, visceral and subcutaneous adipose tissue
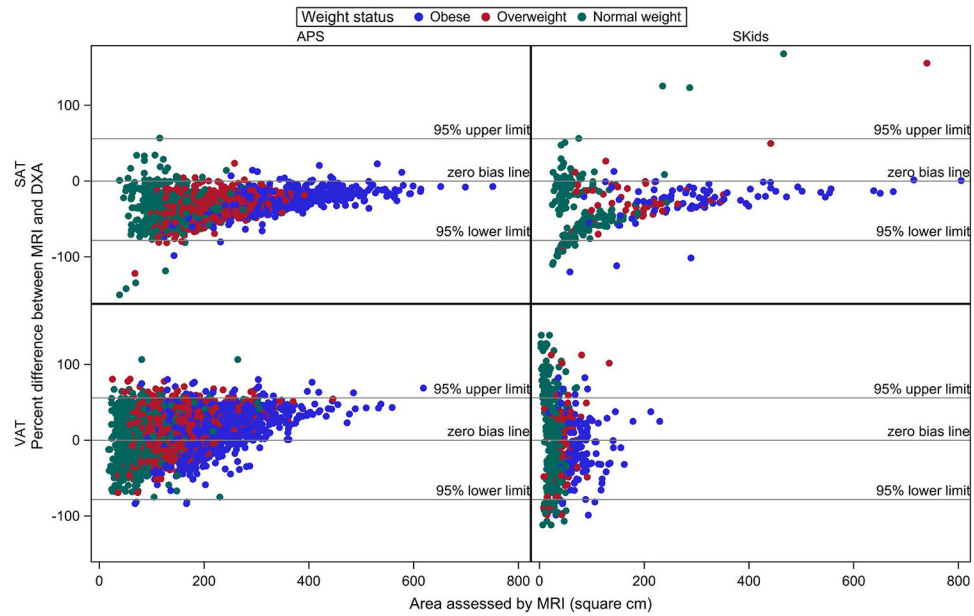
TABLE 1

Characteristics of the APS and Shape Up! Kids participants[a]

Variable	Category	APS			Shape Up! Kids		
		Male	Female	All	Male	Female	All
All		881	914	1,795	134	175	309
Ethnicity	White	208	196	404	49	48	97
	African American	125	175	300	29	46	75
	Latino	188	186	374	10	17	27
	Asian	228	202	430	23	25	48
	NHOPI	132	155	287	24	38	62
BMI status, kg/m^2	<25	235	298	533	82	94	176
	25 to <30	404	322	726	18	35	53
	30	242	294	536	35	45	80
Age[b]	y	69.3 ± 2.8	69.1 ± 2.7	69.2 ± 2.7	12.3 ± 3.2	12.3 ± 3.5	12.3 ± 3.4
MRI SAT[b]	cm^2	193 ± 82	263 ± 107	229 ± 102	137 ± 143	181 ± 137	161 ± 141
DXA SAT[b]	cm^2	263 ± 99	366 ± 114	315 ± 119	144 ± 144	265 ± 154	212 ± 161
MRI VAT[b]	cm^2	202 ± 89	135 ± 62	167 ± 83	41 ± 35	39 ± 23	40 ± 29
DXA VAT[b]	cm^2	153 ± 59	131 ± 57	141 ± 59	45 ± 24	41 ± 32	43 ± 29

Abbreviations: APS, Adiposity Phenotype Study; DXA, dual-energy x-ray absorptiometry; MRI, magnetic resonance imaging; NHOPI, Native Hawaiian/Other Pacific Islander; SAT, subcutaneous adipose tissue; VAT, visceral and subcutaneous adipose tissue.

[a]All analyses were performed separately for each study.

[b]Mean ± SD are presented.

TABLE 2

VAT and SAT values by MRI and DXA in APS and Shape Up! Kids[a]

Group	APS						Shape Up! Kids					
	SAT		VAT				SAT		VAT			
	DXA	MRI	DXA	MRI			DXA	MRI	DXA	MRI		
All	315 ± 119	229 ± 102	141 ± 59	16,783			212 ± 161	161 ± 141	43 ± 29	40 ± 29		
White	288 ± 121	208 ± 94	126 ± 61	158 ± 88			213 ± 164	170 ± 159	48 ± 34	48 ± 38		
African American	369 ± 131	290 ± 119	140 ± 51	146 ± 67			263 ± 200	200 ± 163	46 ± 27	36 ± 21		
Latino	348 ± 109	256 ± 100	172 ± 58	196 ± 86			200 ± 139	155 ± 121	41 ± 27	38 ± 25		
Asian	270 ± 93	178 ± 68	135 ± 55	166 ± 83			161 ± 102	118 ± 93	34 ± 17	32 ± 18		
NHOPI	321 ± 113	235 ± 91	134 ± 56	168 ± 80			195 ± 134	138 ± 111	39 ± 29	40 ± 26		

Abbreviations: APS, Adiposity Phenotype Study; DXA, dual-energy x-ray absorptiometry; MRI, magnetic resonance imaging; NHOPI, Native Hawaiian/Other Pacific Islander; SAT, subcutaneous adipose tissue; VAT, visceral and subcutaneous adipose tissue.

[a]All analyses were performed separately for each study; values shown are mean ± SD.

TABLE 3

Prediction models for MRI-based SAT and VAT from DXA by study[a]

Fat	Predictor	Category	APS Beta	APS p	SKids Beta	SKids p
SAT	Intercept		11.9	0.59	−16.2	0.30
	DXA	cm²	0.71	<0.0001	0.76	<0.0001
		Age, y	−0.21	0.51	3.06	0.01
	Sex (ref = male)	Female	−5.37	0.01	−49.7	<0.0001
	Ethnicity (ref = White)	African American	20.6	<0.0001	−4.24	0.66
		Latino	1.82	0.49	1.59	0.91
		Asian	−15.6	<0.0001	−8.82	0.43
		NHOPI	0.20	0.94	−10.1	0.32
	BMI status (ref < 25 kg/m²)	Overweight	3.9	0.10	26.7	0.01
		Obesity	27.9	<0.0001	23.3	0.12

Model fit statistics			R^2	RMSE	R^2	RMSE
		DXA only	0.854	38.89	0.771	67.70
		DXA plus age, sex	0.858	38.40	0.809	62.07
		Plus ethnicity, BMI	0.876	35.96	0.814	61.88
		Plus biomarkers[b]	0.878	35.70	0.824	63.37

VAT	Intercept		25.2	0.22	−1.2	0.77
	DXA	cm²	1.14	<0.0001	0.64	<0.0001
		Age, y	0.02	0.94	1.11	0.0002
	Sex (ref = male)	Female	−40.2	<0.0001	0.57	0.77
	Ethnicity (ref = White)	African American	−25.8	<0.0001	−11.4	<0.0001
		Latino	−16.4	<0.0001	−5.58	0.12
		Asian	−1.24	0.60	−5.79	0.05
		NHOPI	0.69	0.79	−1.71	0.53
	BMI status (ref < 25 kg/m²)	Overweight	8.39	0.0001	7.25	0.01
		Obesity	13.2	<0.0001	12.7	0.0002

Model fit statistics			R^2	RMSE	R^2	RMSE

DXA only	0.764	40.53	0.640	17.26
DXA plus age, sex	0.822	35.18	0.651	17.06
Plus ethnicity, BMI	0.838	33.67	0.687	16.33
Plus biomarkers [b]	0.841	33.43	0.691	16.89

Abbreviations: APS, Adiposity Phenotype Study; DXA, dual-energy x-ray absorptiometry; MRI, magnetic resonance imaging; NHOPI, Native Hawaiian/Other Pacific Islander; RMSE, root mean square error; SAT, subcutaneous adipose tissue; SKids, Shape Up! Kids; VAT, visceral and subcutaneous adipose tissue.

[a]The results shown were obtained from multiple general regression, separately by study, with MRI-assessed value as dependent variable and adjustment for the age, sex, ethnicity, and BMI.

[b]HDL, LDL, triglycerides, alanine transaminase, and homeostatic model assessment for insulin resistance.