# Clinical Utility and Reproducibility of Visceral Adipose Tissue Measurements Derived from Dual-energy X-ray Absorptiometry in White and African American Adults

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## Abstract

Computed tomography and magnetic resonance imaging are currently used to measure abdominal visceral adipose tissue (VAT) in humans; however, more widely available and less costly dual-energy x-ray absorptiometry (DXA) also has the potential to measure VAT.

**Objective**—The purpose of this study was to determine reproducibility and clinical thresholds for DXA-derived VAT.

**Design and Methods**—The sample included 2317 white and African American adults 18–74 years of age. VAT areas ($cm^2$) were measured using a Hologic DXA scanner equipped with APEX 4.0 software. Reproducibility was assessed using repeated measurements on 101 participants scanned 14 days apart. Receiver Operating Characteristic (ROC) curves were used to assess clinical utility and select thresholds that identified elevated cardiometabolic risk, defined as the presence of 2 risk factors.

**Results**—Reproducibility of DXA-VAT was 8.1%. The areas under the ROC curves ranged from 0.754 in African American men to 0.807 in white women. The thresholds were higher in white men (154 $cm^2$) and women (143 $cm^2$) compared to African American men (101 $cm^2$) and women (114 $cm^2$).

**Conclusion**—The results demonstrate that DXA VAT is a useful clinical marker of cardiometabolic risk; however, further research is required to determine associations with health outcomes using longitudinal studies.

## Keywords

imaging; abdominal obesity; ethnicity; race differences; risk factors

There is considerable evidence that high levels of visceral adipose tissue (VAT) are associated with health risks (1,2). In the past, researchers and clinicians have used imaging techniques such as computed tomography (CT) and magnetic resonance imaging (MRI) to

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measure VAT in humans. However, recent technological advances now allow for the quantification of VAT using widely available dual-energy x-ray absorptiometry (DXA) (3,4). Two validation studies have demonstrated excellent agreement between DXA- and CT-measured VAT (3,4). Kaul and colleagues reported a method of quantifying VAT volume which had a strong association ($r^2 = 0.96$) with CT-measured VAT volume in a sample of 124 men and women (3). Another recent study reported a similar method in which DXA- measured VAT area was strongly associated with CT-measured VAT area ($r^2 = 0.86$) in a sample of 272 South African women (4).

Although several different thresholds for CT and MRI-derived VAT have been published (5–10), clinical thresholds have not been developed for DXA VAT measurements. The purpose of this study was to determine the reproducibility of DXA VAT measurements and derive sex- and race-specific thresholds in a sample of white and African Americans.

## Methods

The sample includes participants from the Pennington Center Longitudinal Study (PCLS) who have enrolled in clinical studies conducted at the Pennington Biomedical Research Center between 1992 and 2012. The current study included 707 white women, 718 African American women, 664 white men and 228 African American men 18–74 years of age. Each participant provided written informed consent and all procedures were approved by the Pennington Biomedical Research Center Institutional Review Board.

Total fat mass (kg), trunk fat mass (kg) and abdominal VAT cross-sectional areas ($cm^2$) were measured using DXA on a whole-body Hologic scanner with APEX software (Version 4.0). The software automatically locates the outer and inner margins of the abdominal wall on both sides of the DXA image based on fat and lean mass profiles in a 5 cm region across the abdomen, with the bottom edge of the region located 1 cm above the iliac crest. The software then measures the total fat mass within the abdominal walls, a region which contains both subcutaneous and visceral fat. The amount of subcutaneous fat between the skin line and outer abdominal wall on both sides of the image is measured, and this estimate is subtracted from the total fat mass measured within the region to yield DXA VAT. These are automated procedures developed by Hologic.

Resting blood pressure measurements were made using a stethoscope and sphygmomanometer or in some cases using a validated Omron automatic measuring device. Serum triglycerides, high-density lipoprotein cholesterol (HDL-C), and glucose were obtained from a 12 hour fasting blood draw. The presence of two or more risk factors defined according to the Harmonized Metabolic Syndrome (11) thresholds [systolic blood pressure 130 or diastolic blood pressure 85 mmHg or reported hypertension, fasting glucose 100 mg/dL or reported diabetes, triglycerides 150 mg/dL, HDL-cholesterol 40 mg/dL (men) or 50 mg/dL (women)] was used to define elevated cardiometabolic risk.

The reproducibility of DXA VAT was assessed in a subsample of 101 participants who underwent two DXA scans 14 days apart. The technical error of measurement (TEM)(12) and the standard error of a single determination (SESD)(13,14) were computed.

Age-adjusted partial correlations were used to assess the association between DXA VAT and risk factors. Differences in DXA VAT across race-by-sex groups were determined using ANCOVA, including age and total fat mass as covariates. Receiver Operating Characteristic (ROC) curves were used to select thresholds that identified individuals with two or more risk factors. Since the area under the curve (AUC) is considered a measure of utility and represents the trade-off between the correct identification of high-risk individuals (sensitivity) and of low-risk individuals (specificity), the threshold was determined from the minimum distance between the ROC curve and the point (0, 1) ($d^2 = [(1 - \text{sensitivity})^2 + (1 - \text{specificity})^2]$) [15]. SAS version 9.3 was used for data management and IBM SPSS version 20.0 was used to perform the ROC analyses. The level of significance was set at p 0.05 for all analyses, and AUCs were considered significant when statistically different from 0.5 [16].

## Results

The average age of the sample was 42.7 years (SD 14.9) and the average BMI was 31.4 kg/m$^2$ (SD 6.0), ranging from 18 to 52 kg/m$^2$. A total of 43%, 37%, 43% and 27% of white women, African American women, white men, and African American men, respectively, had two or more risk factors. The average age of the sub-sample used for reproducibility was 28.8 years (SD 6.7) and the average BMI was 24.1 kg/m$^2$ (SD 3.3), ranging from 18.7 to 31.7 kg/m$^2$.

The TEMs were 13.8 cm$^2$ for VAT, 0.32 kg for trunk fat and 0.35 kg for total fat. The SESD was 8.1% for DXA VAT. This is higher than the SESD for trunk fat (4.1%) and total fat (5.0%) made on the same individuals.

The results of the ANCOVA indicated that there were significant main effects (p<0.0001) for both sex and race for DXA VAT. DXA VAT was higher in men than in women, and higher in whites than in African Americans. Age- and fat mass-adjusted DXA VAT values were 125.1 (SE 1.5) cm$^2$ and 99.7 (SE 1.5) cm$^2$ in white and African American women, respectively, and 167.4 (SE 1.6) cm$^2$ and 141.0 (SE 2.7) cm$^2$ in white and African American men, respectively.

Table 1 presents the age-adjusted partial correlations between DXA VAT and risk factors. DXA VAT was negatively correlated with HDL-C, and positively correlated with the other risk factors. The results of the ROC analyses are presented in Table 2. The AUCs range from 0.754 in African American men to 0.807 in white women. The optimal DXA VAT threshold in the total sample was 126 cm$^2$; however, the thresholds varied across sex-race groups. The thresholds were higher in white men and women by comparison to African American men and women.

## Discussion

The results of this study demonstrate that DXA VAT is a useful clinical marker of cardiometabolic risk. Although waist circumference is highly correlated with total body fat [17], it is also the best anthropometric indicator of VAT [18,19]. However, the use of DXA to derive VAT was shown to significantly improve the standard error of the estimate (SEE)

of predicted VAT from 27 cm$^2$ from a model containing waist circumference and age to 16 cm$^2$ for DXA VAT alone (4). CT and MRI are commonly used to assess VAT; however, DXA offers several advantages, including wider availability, lower costs, and lower exposure to radiation (compared with CT).

The software used in the present study produced a SESD for repeated measurements on the same individuals of 8.1%. This is higher than the SESD for total body fat for the same individuals (5.0%). The lower reproducibility for VAT compared to total body fat is likely due to differences in the positioning of the participant on the DXA table, movement of internal organs, and defining the region of interest for VAT determination; which are less critical for the assessment of total body fat content.

A previous study of sixteen healthy pre-menopausal women reported reproducibility of 3.9% for CT-measured VAT, assessed two times within minutes of each other (14). Further, a study of MRI-measured VAT reported reproducibility of 9.7% among six subjects measured on two occasions, which was higher than the 3% for total fat in that same study (13). The reproducibility of DXA VAT observed in the current study is within the range of other methods of assessing VAT in humans. The issue of reproducibility of DXA VAT and its potential impact on clinical utility deserves further attention.

The optimal VAT threshold in the preset study was 126 cm$^2$ for the overall sample, which is within the range of thresholds (70 cm$^2$ to 144 cm$^2$) from other studies using CT or MRI (5–9). Differences in thresholds across studies are likely due to differences in measurement protocols for VAT (technique, anatomic landmarks, etc.), differences in the outcomes used to assess metabolic risk (insulin resistance, metabolic syndrome, etc.), as well as differences in analytical approaches to determine the thresholds (regression versus ROC analysis).

This study has several strengths and limitations. A marked strength of the study is the large biracial sample of men and women with measurements of DXA VAT and risk factors. Further, the sample had a large range of age and BMI. However, the subsample used for the reliability analysis had a lower mean BMI than the overall sample (24.1 kg/m$^2$ vs 31.4 kg/m$^2$). The sample represents volunteers who have attended screening visits for clinical studies; therefore the results may not be generalizable to other populations. This study is cross-sectional, and cause-and-effect associations between DXA VAT and cardiometabolic risk factors should not be assumed.

The results of this study indicate that DXA VAT is correlated with cardiometabolic risk factors and has good clinical utility in identifying individuals with two or more risk factors. Our study presents thresholds that could be used provisionally to identify those at increased health risk. The lower and upper values around these threshold levels and the impact of age remain to be determined in future research. Further research is required to determine the association between DXA VAT and future health outcomes such as chronic disease incidence and premature mortality rates.

## Acknowledgements

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**What is Already Known About this Subject?**

- visceral fat is associated with metabolic risk

- visceral fat is routinely measured with magnetic resonance imaging or computed tomography

- new methods of assessing visceral fat using dual-energy x-ray absorptiometry (DXA) are now available

**What Does this Study Add?**

- reproducibility of DXA-measured visceral fat levels are presented

- clinical visceral fat thresholds for DXA-measured visceral fat in white and African American adults are provided

**Table 1**

Age-adjusted partial correlations between DXA-measured visceral adipose tissue and cardiometabolic risk factors.

| | SBP | DBP | Glucose | TG | HDL-C |
|---|---|---|---|---|---|
| White Women | 0.23 | 0.26 | 0.31 | 0.37 | −0.44 |
| African American Women | 0.15 | 0.22 | 0.18 | 0.27 | −0.29 |
| White Men | 0.13 | 0.14 | 0.23 | 0.23 | −0.29 |
| African American Men | 0.12[a] | 0.11[a] | 0.21 | 0.08[a] | −0.21 |
| Total Sample | 0.12 | 0.18 | 0.22 | 0.33 | −0.38 |

[a] all correlations are statistically significant (p 0.05) with the exception of those indicated.

SBP: systolic blood pressure; DBP: diastolic blood pressure; GLU: glucose; TG: triglycerides; HDL-C: high density lipoprotein cholesterol.

**Table 2**

Results of Receiver Operating Characteristic (ROC) curve analyses for the utility of DXA-measured visceral adipose tissue (VAT; cm$^2$) predicting the presence of two or more cardiometabolic risk factors.

| | AUC | 95% Confidence Interval | Threshold (cm$^2$) | Sensitivity | Specificity |
|---|---|---|---|---|---|
| White Women | 0.807 | 0.775, 0.838 | 143.1 | 0.73 | 0.75 |
| African American Women | 0.769 | 0.734, 0.803 | 114.3 | 0.73 | 0.68 |
| White Men | 0.767 | 0.731, 0.802 | 153.7 | 0.73 | 0.68 |
| African American Men | 0.754 | 0.680, 0.827 | 101.3 | 0.67 | 0.77 |
| Total Sample | 0.784 | 0.765, 0.802 | 126.0 | 0.76 | 0.68 |