Published in final edited form as:
*Am J Clin Nutr*. 2008 June ; 87(6): 1809–1817.

# Simple anthropometric measures correlate with metabolic risk indicators as strongly as magnetic resonance imaging–measured adipose tissue depots in both HIV-infected and control subjects[2]

**Rebecca Scherzer**, **Wei Shen**, **Peter Bacchetti**, **Donald Kotler**, **Cora E Lewis**, **Michael G Shlipak**, **Steven B Heymsfield**, and **Carl Grunfeld for the Study of Fat Redistribution Metabolic Change in HIV Infection (FRAM)**

*Northern California Institute for Research and Education, San Francisco, CA (RS); the Obesity Research Center, St Luke's–Roosevelt Hospital and the Institute of Human Nutrition, Columbia University College of Physicians and Surgeons, New York, NY (WS); the Department of Epidemiology and Biostatistics, University of California, San Francisco, CA (PB); St Luke's–Roosevelt Hospital Center, New York, NY (DK); the Division of Preventive Medicine, University of Alabama at Birmingham, Birmingham, AL (CEL); the University of California, San Francisco and the Veterans Affairs Medical Center, San Francisco, CA (MGS and CG); and Merck & Co, Rahway, NJ (SBH).*

## Abstract

**Background—**Studies in persons without HIV infection have compared percentage body fat (% BF) and waist circumference as markers of risk for the complications of excess adiposity, but only limited study has been conducted in HIV-infected subjects.

**Objective—**We compared anthropometric and magnetic resonance imaging (MRI)–based adiposity measures as correlates of metabolic complications of adiposity in HIV-infected and control subjects.

**Design—**The study was a cross-sectional analysis of 666 HIV-positive and 242 control subjects in the Fat Redistribution and Metabolic Change in HIV Infection (FRAM) study assessing body mass index (BMI), waist (WC) and hip (HC) circumferences, waist-to-hip ratio (WHR), %BF, and MRI-measured regional adipose tissue. Study outcomes were 3 metabolic risk variables [homeostatic model assessment (HOMA), triglycerides, and HDL cholesterol]. Analyses were stratified by sex and HIV status and adjusted for demographic, lifestyle, and HIV-related factors.

**Results—**In HIV-infected and control subjects, univariate associations with HOMA, triglycerides, and HDL were strongest for WC, MRI-measured visceral adipose tissue, and WHR; in all cases, differences in correlation between the strongest measures for each outcome were small ($r \leq 0.07$). Multivariate adjustment found no significant difference for optimally fitting models between the use of anthropometric and MRI measures, and the magnitudes of differences were small (adjusted $R^2 \leq 0.06$). For HOMA and HDL, WC appeared to be the best anthropometric correlate of metabolic complications, whereas, for triglycerides, the best was WHR.

**Conclusion—**Relations of simple anthropometric measures with HOMA, triglycerides, and HDL cholesterol are approximately as strong as MRI-measured whole-body adipose tissue depots in both HIV-infected and control subjects.

[2]Supported by NIH grants no. RO1-DK57508, HL74814, and HL 53359 and NIH GCRC grants no. M01-RR00036, RR00051, RR00052, RR00054, RR00083, RR0636, and RR00865.

Reprints not available. Address correspondence to C Grunfeld, University of California, San Francisco, Veterans Affairs Medical Center, Metabolism Section 111F, 4150 Clement Street, San Francisco, CA 94121. E-mail: carl.grunfeld@ucsf.edu..

## INTRODUCTION

Several studies have implicated abdominal obesity as a stronger predictor than overall obesity of insulin resistance and dyslipidemia in the general population (1,2). Shen et al (3) found that waist circumference (WC) is more highly correlated with metabolic syndrome components than is percentage body fat (%BF) and other related anthropometric measures, such as body mass index (BMI) and waist-to-hip ratio (WHR). Another study (4) also reported that WC was more highly correlated than other anthropometric measures with insulin resistance in men, and that the addition of dual-energy X-ray absorptiometry measures offered little improvement in prediction in men or women. Whereas metabolic syndrome definitions of the Adult Treatment Panel III and the American Association of Clinical Endocrinologists do not include insulin resistance, other definitions do. Indeed, the definitions of the World Health Organization and the European Group for the Study of Insulin Resistance include homeostatic model assessment (HOMA) or insulin resistance as one of the required components (5).

In the setting of HIV infection, the introduction of combination antiretroviral therapy was followed by the observation of changes in fat distribution and metabolic abnormalities (6). HIV infection has been associated with a syndrome of lipoatrophy, which is characterized by the loss of subcutaneous adipose tissue; the legs and lower trunk are most affected in men and women, and the upper trunk is less affected (7,8). HIV lipoatrophy is not accompanied by a reciprocal increase in visceral adipose tissue (VAT) (7,8). HIV-associated lipodystrophy has been associated with adverse metabolic variables that predict greater risk of cardiovascular disease (9,10). The loss of fat in the lower trunk raises the question of whether WC and WHR are accurate predictors of metabolic abnormalities in patients with HIV infection.

To date, no study in HIV-infected subjects has compared anthropometric measures and total fat as predictors of metabolic abnormalities. Furthermore, no study has compared anthropometric and whole-body MRI-measured regional adipose tissue volumes as correlates of metabolic complications of adiposity in either HIV-infected or -noninfected subjects. A primary aim of the Fat Redistribution and Metabolic Change in HIV Infection (FRAM) study, a large, nationally representative, multiethnic cohort study of HIV-infected subjects and control subjects, was to determine in the setting of HIV-associated lipoatrophy whether traditional anthropometric measures are as strong as whole-body regional MRI measures of adiposity in predicting metabolic abnormalities.

## SUBJECTS AND METHODS

### Protocol and subjects

The primary study aim was to evaluate the associations of anthropometric measures and MRI adipose tissue depots with 3 metabolic risk indicators—insulin resistance, triglycerides, and HDL cholesterol. Given previous findings that abnormal metabolic outcomes were associated with changes in HIV-related peripheral lipoatrophy, we sought to compare body-composition associations with metabolic indicators in both HIV-infected subjects and control subjects.

The FRAM study enrolled 1175 HIV-infected subjects and 297 uninfected control subjects, both men and women, between 2000 and 2002. FRAM was designed to evaluate the prevalence and correlates of changes in fat distribution, insulin resistance, and dyslipidemia in a representative sample of HIV-infected subjects and uninfected controls in the United States. Methods were described previously in detail (11). HIV-infected subjects were recruited from 16 HIV or infectious disease clinics or cohorts. Control subjects were recruited from 2 centers of the Coronary Artery Risk Development in Young Adults (CARDIA) study (12). CARDIA subjects were originally (1985−1986) recruited as a sample of healthy 18−30-y-old white and

African American men and women from 4 cities for a longitudinal study of cardiovascular risk factors.

Subjects taking hypolipidemic drugs ($n$ = 185) were excluded, because those drugs influence triglycerides and HDL. Those with diabetes ($n$ = 106) also were excluded, because fasting insulin measurements are less accurate predictors of insulin resistance in such subjects. Diabetes was defined as a fasting blood glucose concentration ≥ 126 mg/dL (7.0 mmol/L) or the current use of hypoglycemic medication. MRIs were performed for 92% of the FRAM study participants. To facilitate comparison, all models under comparison for a given risk factor contained exactly the same observations. Therefore, we report here on the subset of 242 control subjects and 666 HIV-infected subjects for whom there were measurements of adipose tissue depots by MRI and anthropometric measurements and information on glucose, insulin, triglyceride, and HDL cholesterol concentrations.

Written informed consent had been obtained from all participants before the beginning of the FRAM study. The study protocol was approved by the institutional review boards of all study site institutions.

## Body composition

**Anthropometric measurements—**All staff members were centrally trained and certified for measurements. All anthropmetric measurements were conducted according to a standard procedure (13). Subjects wore light clothing or a hospital gown and no shoes. Height was measured to the nearest 0.1 inch or 0.1 cm, and weight was measured to the nearest 0.1 pound or 0.1 kg by using calibrated stadiometers and scales, respectively. BMI (in kg/m$^2$) was calculated. WC was measured in the midaxillary line immediately below the lowest rib. Hip circumference (HC) was measured at the maximum extension of the buttocks as viewed from the side. WHR was calculated as WC/HC.

**Magnetic resonance imaging—**Whole-body MRI was performed to quantify regional and total adipose tissue (14). Body composition was measured while the subjects were in the supine position and had their arms extended overhead, and it was analyzed as described in detail elsewhere (7,8,11,14). In brief, by using the space between the fourth and fifth lumbar vertebrae as the origin, transverse images (10-mm slice thickness) were obtained every 40 mm from hand to foot. MRI scans were segmented by using image analysis software (Tomovision Inc, Montreal, Canada). A single image-reading center was used to read all scans, and imaging techniques and anatomical sites (based on bone landmarks) were identical between HIV-infected subjects and control subjects. The MRI scan acquisition protocol was standardized across sites, and the image-reading center performed site visits to ensure protocol adherence. Scans were sent to the image-reading center (Obesity Research Center, St Luke's–Roosevelt Hospital, New York, NY), where tissue areas (cm$^2$) were calculated by summing specific tissue pixels and then multiplying by individual pixel surface area. The volume per slice (cm$^3$) of each tissue was calculated by multiplying area by thickness. The volume of each tissue for the space between 2 consecutive slices was calculated by using a mathematical algorithm (15). Anatomic sites considered in this analysis were upper trunk, lower trunk, arm, leg, and total subcutaneous adipose tissue (SAT), VAT, and total adipose tissue. The upper limit of lower trunk is the last slice at which the liver area is greater than the lung, whereas the lower limit of upper trunk is the first slice at which the lung area is greater than the liver. Because adipose tissue has a density of 0.92 g/cm$^3$, the %BF was calculated as 100 × 0.92 g/cm$^3$ × the ratio of total adipose tissue volume to body weight.

### Blood studies

Fasting serum glucose and lipids (total cholesterol, triglycerides, and HDL cholesterol) were measured centrally (Covance, Indianapolis, IN), as were fasting insulin concentrations (Linco Research Inc, St Louis, MO). Insulin resistance was assessed by using HOMA, which was derived as insulin × glucose /22.5, with insulin measured in μU/mL and glucose in mmol/L.

### Other measurements

Standardized questionnaire instruments were used to assess physical activity, alcohol intake, smoking, the use of illicit drugs, and the adequacy of food intake of FRAM participants (11, 12). Food intake was based on self-reporting from a validated instrument; subjects were asked whether they had adequate access to the food needed or adequate resources to obtain the food. Medical history also was assessed. Research associates interviewed HIV-infected participants and reviewed medical charts to determine the dates of use of individual antiretroviral medications.

### Statistical analysis

Separate analyses were conducted for HIV-infected men, HIV-infected women, control men, and control women. Spear-man correlation coefficients were calculated to examine the relation of each body-composition measure with each risk factor (HOMA, triglycerides, and HDL cholesterol), because many measures were nonnormally distributed. Correlations were compared between HIV-infected and control subjects by using Fisher's *z* test.

Multivariate regression equations were calculated with HOMA, triglycerides, or HDL as the dependent variable for HIV-infected and control men and women separately. Base models were constructed for each outcome by using demographics (age and race-ethnicity), lifestyle factors, and HIV-related factors as potential predictor variables. Age and race-ethnicity were forced into every model; HIV RNA concentration (log 10) and CD4 count (log 2) were forced into the HIV models because they are known to have opposite effects (16). Candidate lifestyle factors included physical activity, smoking status, alcohol use, adequate food intake, and the use of illicit drugs. Candidate HIV-related factors (tested only for HIV models) included AIDS diagnosis (by CD4 count or opportunistic infection), reported HIV duration, hepatitis C infection (by virus detection), days since last opportunistic infection, recent opportunistic infection status (past 100 d), and HIV risk factors. In multivariate models after control for the above factors, we evaluated current use of each individual antiretroviral drug and its class: ie, nucleoside reverse transcriptase inhibitor, nonnucleoside reverse transcriptase inhibitor, protease inhibitor, or highly active antiretroviral therapy, as previously defined (7).

Because of their skewed distribution, HOMA, triglycerides, and HDL were log transformed in all linear regression analyses. Models were built in a forward stepwise manner, with $P = 0.05$ for entry and retention. Interactions with race-ethnicity and age were assessed and included if they were significant.

Anthropometric measures and adipose tissue depots (as described above) were tested in the model after construction of the base model for each outcome. Within each stratum, a single base model (ie, the same set of predictors) was used for each outcome (ie, HOMA, triglycerides, or HDL cholesterol). Because of their skewed distribution, adipose tissue measures were log transformed. Collinearity was assessed among adipose measures in all models, but it was not substantial. The linearity assumption was tested for continuous measures by adding quadratic terms to the models and examining generalized additive models (17). Because we have analyzed height-normalized depots in past analyses (7,8), in this analysis, we tested log(height) and retained it when it improved model fit.

We identified the overall best-fitting model for each risk factor and each subpopulation (HIV-infected and control men and women) and also the best-fitting model within each category (anthropometric or MRI) by calculating the adjusted $R^2$ for each model. Using the same base model, we then tested whether adding the best MRI depots to the best anthropometric models would improve the fit. Finally, using a bias-corrected accelerated bootstrapping procedure (18), we obtained 95% CIs for how much the best combination (MRI + anthropometric) improved the fit over the best-fitting MRI-only and anthropometric-only models. The improvement was considered significant if the 95% CI contained only positive numbers. All analyses were conducted by using SAS software (version 9.1; SAS Institute Inc, Cary, NC).

# RESULTS

## Subjects

Information on insulin, lipids, and body composition was available for 908 subjects whose characteristics are presented in Table 1. Total fat, leg, lower trunk, and arm SAT were higher in control subjects, and VAT, upper trunk SAT, and WC were higher in control men than in HIV-infected men. Triglycerides were higher and HDL was lower in HIV-infected subjects than in control subjects of both sexes, whereas insulin and HOMA were higher in HIV-infected than in control women.

## Associations between body composition and homeostatic model assessment

Univariate correlation coefficients between body composition and HOMA are summarized in Table 2. Whereas nearly all adipose tissue depots and anthropometric measurements were strongly associated with HOMA, WC had the highest correlation ($r = 0.32-0.68$, $P < 0.0001$). The lowest correlation in all 4 subgroups was that for leg SAT with HOMA, particularly in HIV-infected subjects. Among regional depots, the strongest associations were generally seen with upper trunk (UT) SAT and VAT. Correlations were stronger in controls than in HIV-infected subjects, both men and women ($P < 0.05$ and $P < 0.001$, respectively, for most comparisons).

After multivariate adjustment for demographics and lifestyle factors, the strongest MRI variable combinations for association with HOMA contained VAT or UT with leg or lower trunk (LT) SAT (Table 2). Among anthropometric measures, the strongest combinations included WC or WHR, usually with BMI, although WC alone was nearly as strong. As in the univariate case, associations were stronger for control subjects than for HIV-infected subjects ($P < 0.05$ for nearly every case). Adjusted $R^2$ values for the best anthropometric combinations were similar to the best MRI combinations, and no significant differences were found between best-fitting anthropometric and MRI models ($P = 0.65$ in HIV-positive men, $P = 0.32$ in HIV-positive women, $P = 0.19$ in control men, and $P = 0.65$ in control women).

When anthropometric and MRI measurements were combined in the same model, the best-fitting models for HOMA always contained VAT with WC or WHR (Table 2); adjusted $R^2$ values were slightly larger than those in the models containing only MRI or anthropometric measures, with significant differences only in HIV-infected men. Further adjustment for HIV-related factors and use of antiretrovirals did not change these findings (data not shown).

## Associations between body composition and triglycerides

In univariate analyses in control men and women and in HIV-infected women, VAT had the highest correlation with triglycerides ($r = 0.41-0.42$, $P < 0.0001$), whereas WHR was highest in HIV-infected men ($r = 0.44$, $P < 0.0001$; Table 3). In all 4 subgroups, both VAT and WHR were strongly correlated ($r = 0.37-0.44$, $P < 0.0001$) with triglycerides, whereas WC was nearly as strong ($r = 0.30-0.39$, $P < 0.001$). In HIV-infected subjects but not in control subjects, leg

SAT was negatively correlated with triglycerides, whereas all other body-composition measures were positively correlated. In control men and women, the weakest correlations were also observed with leg SAT. Correlations were generally stronger in control subjects than in HIV-infected subjects.

After multivariate adjustment, the strongest MRI combinations all contained leg and UT SAT (Table 3), usually in combination with VAT. The best anthropometric combinations all included a measure of central adiposity (WC, HC, or WHR). Adjusted $R^2$ values for the best anthropometric combinations were quantitatively similar to the best MRI combinations, and no significant differences were found between best-fitting MRI and anthropometric models ($P > 0.80$ in HIV-infected men and women, $P = 0.46$ in control men, and $P = 0.23$ in control women).

When anthropometric and MRI measurements were combined in the same model, the best-fitting models for triglycerides typically contained VAT with WC or WHR (Table 3). Adjusted $R^2$ values were usually slightly higher than those in the models containing only MRI or anthropometric measures, although the difference was significant only in HIV-infected subjects. Further adjustment for HIV-related factors and use of antiretrovirals did not change these findings (data not shown).

### Associations between body composition and HDL cholesterol

In univariate analyses, VAT had the highest correlation with HDL in men ($r = -0.26$ and $r = -0.36$ in HIV-positive and control subjects, respectively; $P < 0.0001$) and in HIV-infected women ($r = -0.19$, $P = 0.007$), whereas WC was strongest in control women ($r = -0.48$, $P < 0.0001$; Table 4). All measures were negatively correlated with HDL except leg SAT in HIV-infected men, which showed a weak positive correlation. Weak correlations with leg SAT also were observed in HIV-infected women and control men and women. Correlations in control subjects were significantly ($P < 0.05$) stronger than those in HIV-infected subjects.

After multivariate adjustment (Table 4), the strongest MRI combinations included VAT in all subgroups but control men (in whom LT SAT was strongest, but VAT was similar). The best anthropometric combinations all included WC, a measure of central adiposity, or HC. Although univariate correlations were usually stronger in controls than in HIV-infected subjects, the difference was not significant after multivariate adjustment. Adjusted $R^2$ values for the best anthropometric combinations were similar to those in the best MRI combinations, and no significant differences were found ($P > 0.80$ in HIV-infected men and women, $P = 0.67$ in control men, and $P = 0.19$ in control women). Further adjustment for HIV-related factors and use of antiretrovirals did not change these findings (data not shown).

When anthropometric and MRI measurements were combined in the same model, adjusted $R^2$ values for combination models in HIV-infected subjects were slightly higher than those in the models containing only MRI or anthropometric measures. However, the difference was significant only in HIV-infected men.

### Improvement of association with metabolic health risks by combining magnetic resonance imaging measures and anthropometric measures in regression models

In testing whether the addition of MRI measures improves the prediction after anthropometric measures have been entered, MRI measures made a small but significant contribution among HIV-infected subjects: for HOMA and triglycerides in men and for triglycerides in women (adjusted $R^2$ improvement of 2.3–5.1%; Tables 2–3). Adding MRI measures to anthropometric measures did not lead to a significant improvement in control subjects. When anthropometric measures were added after MRI measures, the anthropometric measures made a significant

contribution to MRI models in 4 instances, again only in HIV-infected subjects: for HOMA and triglycerides in men; and for trigycerides and HDL in women (adjusted $R^2$ improvement of 3.3−6.7%; Tables 2–4).

Base models, which included demographics and lifestyle factors but excluded adiposity measures, explained 2−19% of the variance for HOMA, triglycerides, and HDL (Tables 2–4). Compared with base models, the best anthropometric + MRI combinations explained 6−40% more of the total variation in men and 11−35% more of the total variation in women. To assess the possibility that MRI associations could have been weakened by separation into too many regional components, we also evaluated the combination of VAT + total SAT. However, in each case, VAT + total SAT was not as strong as the best MRI combination.

Finally, we compared best-fitting models with WC, WHR, and VAT alone (Table 5). In HIV-infected men, the best-fitting combinations were stronger (ie, had larger adjusted $R^2$; $P < 0.05$) than WC, WHR, or VAT alone in all but 2 cases. Results were mixed for all women and control men. For HOMA, the best-fitting combinations often were stronger than VAT and WHR but similar to WC. For triglycerides, the best-fitting combinations tended to be stronger than WC, WHR, and VAT in HIV-infected and control women, but they showed little improvement in control men. For HDL, the best-fitting combinations were stronger than WHR in HIV-infected women and control men, but they offered little improvement over WC and VAT in other subgroups. The best-fitting MRI models were stronger than WC or WHR in very few cases. Likewise, the best-fitting anthropometric models were stronger than VAT only for HOMA in all men and for triglycerides in control women.

## DISCUSSION

Our main finding was that associations of anthropometric measures with metabolic risk indicators were similar to those for full regional adipose tissue volumes from MRI in both HIV-infected and control populations. In particular, WC appeared to be the best anthropometric measure of visceral obesity for HOMA and HDL, whereas, for triglycerides, the best anthropometric measure was WHR. The %BF was consistently weaker than WC, WHR, and most other predictors. After multivariate adjustment for demographic and lifestyle factors, there was no significant difference in adjusted $R^2$ between best-fitting models using anthropometric or MRI measures. Further adjustment for HIV-related factors and use of antiretrovirals did not change this finding. Thus, WC and WHR remain reasonable surrogates, despite the fact that HIV-infected persons have less leg and LT fat, without a compensatory increase in VAT.

The addition of MRI measures to the anthropometric measures significantly improved model fit in 3 analyses in HIV-infected subjects (ie, HOMA and triglycerides in men and trigycerides in women) but in none of the analyses in controls. The improvement in adjusted $R^2$, however, was $\leq 0.05$, even when it was significant. Likewise, the addition of anthropometrics to the MRI model offered little improvement in adjusted $R^2$.

Our finding that WC and WHR are strongly associated with metabolic risk indicators is supported by previous work in smaller studies of HIV-infected subjects that used more-limited body-composition measurements. Meininger et al (19) found WHR to be a stronger predictor of hyperinsulinemia than were other anthropometric measures (eg, WC, HC, and BMI), dual-energy X-ray absorptiometry variables (extremity and trunk fat), and computerized tomography–measured VAT and abdominal SAT in 41 HIV-infected men. Similarly, Dolan et al (20) found that WHR was a stronger predictor of several metabolic syndrome components (ie, insulin, glucose, triglycerides, and HDL) than were other anthropometric, dual-energy X-ray absorptiometry, and computerized tomography measures in 100 HIV-infected women.

Shen et al (3) reported that %BF did not correlate as well as did WC with health risk indicators in a large cohort of HIV-uninfected persons. Our results also show that %BF is less predictive of metabolic complications than are other anthropometric and MRI measures in both HIV-infected and control subjects. Our MRI measures included depots not traditionally quantified, such as UT and LT, which did enter some models.

Our finding that WC appears to be correlated with health risk indicators at least as strongly as is VAT was previously observed in HIV-uninfected subjects (3,21). One explanation for this finding is that even MRI-measured VAT has a fair amount of measurement error (21), which exceeds that for WC measurements done by trained personnel, and thus the strong associations with WC may reflect greater precision of measurement. It is also possible that, if abdominal size by the supine sagittal diameter or an alternative site for WC were used, this measure may have correlated even more strongly with metabolic outcomes. However, longitudinal studies of weight-loss intervention (22) and diabetes prevention (23) have shown a greater percentage reduction in VAT than in WC. The relation of VAT with health risk indicators has been studied (24–27), but further work is needed to understand the mechanisms involved, particularly in longitudinal intervention studies.

Correlations were generally stronger in control subjects than in HIV-infected subjects, particularly for HOMA, whose association was significantly higher in control subjects than in the HIV-infected group for nearly every measure of body composition. The MRI + anthropometric combination models were more often stronger than WC, WHR, or VAT in HIV-infected subjects than in control subjects. This difference between HIV-infected and control subject may be due to abnormalities in fat distribution found in HIV infection. The loss of abdominal subcutaneous fat in HIV infection (7,8) may decrease the utility of WC as a predictor of the deleterious effects of obesity. Likewise, the presence of severe subcutaneous lipoatrophy may affect the contribution of those depots, especially leg SAT. Of note, 3 of the 4 best MRI and combined models included leg SAT, the depot most affected in HIV infection (7,8), which was negatively associated with HOMA and triglycerides in multivariate analysis; negative associations of leg SAT with HOMA and triglycerides were reported previously (9, 10,28). Thus, the normal relation between adipose tissue and metabolic health risk indicators may be somewhat weakened or altered in HIV-infected subjects, because of the presence of lipoatrophy. Other reports have found that thigh circumference is associated with improved metabolic indicators (29), and thus it is possible that the use of a measure of midthigh circumference as a surrogate for leg SAT could improve the predictive ability of the anthropometric measures. However, given the presence of HIV-associated peripheral lipoatrophy (7,8), it is likely that thigh circumference would be more reflective of lower limb lean mass. Finally, other HIV-related factors that cause insulin resistance may weaken the relation of adipose tissue with HOMA.

The present study has several limitations. The cross-sectional design limits the ability to determine causality of body composition and metabolic risk indicators. There may have been inadequate control for factors that confounded the association of body composition with metabolic outcomes. The amount of VAT in our cohort is somewhat smaller than that in a previously reported study of HIV-uninfected subjects (21,30): medians of 1.9 and 0.9 L in control men and women in this study compared with medians of 2.3 and 1.1 L in corresponding subjects. This difference may explain in part the lower correlation between health risks and VAT seen in the present study. We used a single fasting specimen; insulin is known to be secreted in a pulsatile manner, and thus basal concentrations may be variable.

An important question is whether our findings in HIV-infected subjects and controls will be validated with other obesity-related health risks, development of diabetes, and mortality. A 12-wk study of a small number of obese HIV-infected women (31) found no improvement in

insulin sensitivity, despite the loss of VAT and total body weight. A prospective study of the evolution of metabolic risk indicators in large HIV-infected populations may help address causality concerns.

### Conclusions

Simple anthropometric measures had associations with health risk indicators that appeared to be about as strong as MRI-based measures in both HIV-infected subjects and control subjects. For HOMA and HDL, WC appeared to be the best anthropometric correlate of metabolic complications, whereas, for triglycerides, the best was WHR. The addition of MRI depots to the anthropometric models produced only small improvements in model fit. As in control subjects, the effect of adiposity on health risks is better captured by central adiposity measures than by %BF in HIV-infected subjects. A critical question emerging from these observations is that of how best to define and screen for obesity in HIV infection, considering energy stores on the one hand and health risks on the other. Our data suggest that, despite the presence of HIV-associated lipoatrophy, the use of WC and HC is a highly effective screening method, which may be particularly useful in resource-limited and clinical settings. Data are also needed in longitudinally monitored HIV-infected populations, including health risks other than metabolic risk indicators.

## Acknowledgements

The funder played no role in the conduct of the study, collection of the data, management of the study, analysis of data, interpretation of the data or preparation of the manuscript. A representative of the funding agent participated in planning the protocol. As part of the standard operating procedures of the Coronary Artery Risk Development in Young Adults (CARDIA) study, the manuscript was reviewed at the National Heart, Lung, and Blood Institute, but no revisions were requested.

We thank the following institutions and persons for their roles in the study. Sites and Investigators: University Hospitals of Cleveland (Barbara Gripshover, MD); Tufts University (Abby Shevitz, MD, and Christine Wanke, MD); Stanford University (Andrew Zolopa, MD, and Lisa Gooze, MD); University of Alabama at Birmingham (Michael Saag, MD, and Barbara Smith, PhD); Johns Hopkins University (Joseph Cofrancesco and Adrian Dobs); University of Colorado Health Sciences Center (Constance Benson, MD, and Lisa Kosmiski, MD); University of North Carolina at Chapel Hill (Charles van der Horst, MD); University of California at San Diego (W Christopher Mathews, MD, and Daniel Lee, MD); Washington University (William Powderly, MD, and Kevin Yarasheski, PhD); VA Medical Center, Atlanta (David Rimland, MD); University of California at Los Angeles (Judith Currier, MD, and Matthew Leibowitz, MD); VA Medical Center, NY (Michael Simberkoff, MD, and Juan Bandres, MD); VA Medical Center, Washington, DC (Cynthia Gilbert, MD, and Fred Gordin, MD); St Luke's–Roosevelt Hospital Center (Donald Kotler, MD, and Ellen Engelson, PhD); University of California at San Francisco (Morris Schambelan, MD, and Kathleen Mulligan, PhD); Indiana University (Michael Dube, MD); Kaiser Permanente, Oakland (Stephen Sidney, MD); and University of Alabama at Birmingham (Cora E Lewis, MD). Data Coordinating Center: University of Alabama, Birmingham (O Dale Williams, PhD, Heather McCreath, PhD, Charles Katholi, PhD, George Howard, PhD, Tekeda Ferguson, and Anthony Goudie). Image Reading Center: St Luke's–Roosevelt Hospital Center (Steven Heymsfield, MD, Jack Wang, MS, and Mark Punyanitya). Office of the Principal Investigator: University of California, San Francisco, Veterans Affairs Medical Center and the Northern California Institute for Research and Development (Carl Grunfeld, MD, PhD, Phyllis Tien, MD, Peter Bacchetti, PhD, Dennis Osmond, PhD, Andrew Avins, MD, Michael Shlipak, MD, Rebecca Scherzer, PhD, Mae Pang, RN, MSN, Heather Southwell, MS, RD, Erin Madden, MPH, and Yong Kyoo Chang, MS).

The authors' responsibilities were as follows—RS: analysis and interpretation of data, statistical analysis, writing the manuscript draft, and critical revision of the manuscript for intellectual content; SBH and WS: conception and design of the study, obtained funding, analysis and interpretation of data, and critical revision of the manuscript for important intellectual content; PB, DK, CEL, and MGS: conception and design of the study, analysis and interpretation of data, statistical analysis, and critical revision of the manuscript for important intellectual content; and CG: conception and design of the study, analysis and interpretation of data, obtained funding, statistical analysis, writing the manuscript draft, and critical revision of the manuscript for intellectual content. None of the authors had a personal or financial conflict of interest.

## REFERENCES

1. Despres JP. Health consequences of visceral obesity. Ann Med 2001;33:534–41. [PubMed: 11730160]

2. Concepcion L, Marti-Bonmati L, Aliaga R, Delgado F, Morillas C, Hernandez A. [Abdominal fat assessment by magnetic resonance: comparison with biometric profiles and cardiovascular risk markers.]. Med Clin (Barc) 2001;117:366–9. [PubMed: 11602154](in Spanish)
3. Shen W, Punyanitya M, Chen J, et al. Waist circumference correlates with metabolic syndrome indicators better than percentage fat. Obesity (Silver Spring) 2006;14:727–36. [PubMed: 16741276]
4. Sierra-Johnson J, Johnson BD, Bailey KR, Turner ST. Relationships between insulin sensitivity and measures of body fat in asymptomatic men and women. Obes Res 2004;12:2070–7. [PubMed: 15687409]
5. Bloomgarden ZT. Definitions of the insulin resistance syndrome: the 1st World Congress on the Insulin Resistance Syndrome. Diabetes Care 2004;27:824–30. [PubMed: 14988311]
6. Safrin S, Grunfeld C. Fat distribution and metabolic changes in patients with HIV infection. AIDS 1999;13:2493–505. [PubMed: 10630518]
7. Bacchetti P, Gripshover B, Grunfeld C, et al. Fat distribution in men with HIV infection. J Acquir Immune Defic Syndr 2005;40:121–31. [PubMed: 16186728]
8. Bacchetti P, Cofrancesco J, Heymsfield S, et al. Fat distribution in women with HIV infection. J Acquir Immune Defic Syndr 2006;42:562–71. [PubMed: 16837863]
9. Currier J, Scherzer R, Bacchetti P, et al. Regional adipose tissue and lipid and lipoprotein levels in HIV-infected women. J Acquir Immune Defic Syndr. Jan 11;2008 (Epub ahead of print)
10. Wohl D, Scherzer R, Heymsfield S, et al. The associations of regional adipose tissue with lipid and lipoprotein levels in HIV-infected men. J Acquir Immune Defic Syndr. Mar 20;2008 (Epub ahead of print)
11. Tien PC, Benson C, Zolopa AR, Sidney S, Osmond D, Grunfeld C. The study of fat redistribution and metabolic change in HIV infection (FRAM): methods, design, and sample characteristics. Am J Epidemiol 2006;163:860–9. [PubMed: 16524955]
12. Friedman GD, Cutter GR, Donahue RP, et al. CARDIA: study design, recruitment, and some characteristics of the examined subjects. J Clin Epidemiol 1988;41:1105–16. [PubMed: 3204420]
13. Lohman, T.; Roche, A.; Martorell, R., editors. Anthropometric standardization reference manual. abridged edition.. Human Kinetics Books; Champaign, IL: 1988.
14. Gallagher D, Belmonte D, Deurenberg P, et al. Organ-tissue mass measurement allows modeling of REE and metabolically active tissue mass. Am J Physiol 1998;275:E249–58. [PubMed: 9688626]
15. Shen W, Wang Z, Tang H, et al. Volume estimates by imaging methods: model comparisons with visible woman as the reference. Obes Res 2003;11:217–25. [PubMed: 12582217]
16. El-Sadr WM, Mullin CM, Carr A, et al. Effects of HIV disease on lipid, glucose and insulin levels: results from a large antiretroviral-naive cohort. HIV Med 2005;6:114–21. [PubMed: 15807717]
17. Hastie, T.; Tibshirani, R. Generalized additive models. Chapman and Hall; New York, NY: 1990.
18. Efron, B.; Tibshirani, R. An introduction to the bootstrap. Chapman and Hall; London, United Kingdom: 1993.
19. Meininger G, Hadigan C, Rietschel P, Grinspoon S. Body-composition measurements as predictors of glucose and insulin abnormalities in HIV-positive men. Am J Clin Nutr 2002;76:460–5. [PubMed: 12145023]
20. Dolan SE, Hadigan C, Killilea KM, et al. Increased cardiovascular disease risk indices in HIV-infected women. J Acquir Immune Defic Syndr 2005;39:44–54. [PubMed: 15851913]
21. Shen W, Punyanitya M, Chen J, et al. Visceral adipose tissue: relationships between single slice areas at different locations and obesity-related health risks. Int J Obes (Lond) 2007;31:763–9. [PubMed: 17060927]
22. Lin E, Phillips LS, Ziegler TR, et al. Increases in adiponectin predict improved liver, but not peripheral, insulin sensitivity in severely obese women during weight loss. Diabetes 2007;56:735–42. [PubMed: 17327444]
23. Fujimoto WY, Jablonski KA, Bray GA, et al. Body size and shape changes and the risk of diabetes in the diabetes prevention program. Diabetes 2007;56:1680–5. [PubMed: 17363740]
24. Sahyoun NR, Anderson AL, Kanaya AM, et al. Dietary glycemic index and load, measures of glucose metabolism, and body fat distribution in older adults. Am J Clin Nutr 2005;82:547–52. [PubMed: 16155266]

25. Nicklas BJ, Penninx BW, Cesari M, et al. Association of visceral adipose tissue with incident myocardial infarction in older men and women: the Health, Aging and Body Composition Study. Am J Epidemiol 2004;160:741–9. [PubMed: 15466496]

26. Snijder MB, van Dam RM, Visser M, Seidell JC. What aspects of body fat are particularly hazardous and how do we measure them? Int J Epidemiol 2006;35:83–92. [PubMed: 16339600]

27. Liu KH, Chan YL, Chan WB, Kong WL, Kong MO, Chan JC. Sonographic measurement of mesenteric fat thickness is a good correlate with cardiovascular risk factors: comparison with subcutaneous and preperitoneal fat thickness, magnetic resonance imaging and anthropometric indexes. Int J Obes Relat Metab Disord 2003;27:1267–73. [PubMed: 14513076]

28. Mynarcik DC, McNurlan MA, Steigbigel RT, Fuhrer J, Gelato MC. Association of severe insulin resistance with both loss of limb fat and elevated serum tumor necrosis factor receptor levels in HIV lipodystrophy. J Acquir Immune Defic Syndr 2000;25:312–21. [PubMed: 11114831]

29. Snijder MB, Dekker JM, Visser M, et al. Larger thigh and hip circumferences are associated with better glucose tolerance: the Hoorn study. Obes Res 2003;11:104–11. [PubMed: 12529492]

30. Shen W, Punyanitya M, Wang Z, et al. Visceral adipose tissue: relations between single-slice areas and total volume. Am J Clin Nutr 2004;80:271–8. [PubMed: 15277145]

31. Engelson ES, Agin D, Kenya S, et al. Body composition and metabolic effects of a diet and exercise weight loss regimen on obese, HIV-infected women. Metabolism 2006;55:1327–36. [PubMed: 16979403]

## TABLE 1

Subject characteristics for HIV-infected (HIV+) and control men and women[1]

| | HIV+ men (*n* = 467) | Control men (*n* = 129) | HIV+ women (*n* = 199) | Control women (*n* = 113) |
|---|---|---|---|---|
| Age (y) | 42 (37–47)[2] | 40 (38–43)[3] | 40 (34–46) | 42 (38–44) |
| Race-ethinicity (%) | | | | |
| White | 55 | 57[2] | 35 | 55[3] |
| African American | 33 | 43 | 54 | 45 |
| Hispanic | 10 | | 9 | |
| Other | 2 | | 3 | |
| Anthropometric measures | | | | |
| BMI (kg/m$^2$) | 24 (22–26) | 27 (24–30)[3] | 25 (22–30) | 28 (23–33) |
| WC (cm) | 87 (82–95) | 91 (86–97)[3] | 85 (77–94) | 85 (74–95) |
| HC (cm) | 94 (90–98) | 102 (98–108)[3] | 98 (91–107) | 105 (98–116)[3] |
| WHR | 0.93 (0.90–0.99) | 0.89 (0.85–0.93)[3] | 0.85 (0.80–0.91) | 0.77 (0.74–0.82)[3] |
| MRI adipose tissue depots[4] | | | | |
| VAT (L) | 1.5 (0.7–2.9) | 1.9 (1.1–3.1)[3] | 1.1 (0.5–1.6) | 0.9 (0.4–1.6) |
| Upper trunk SAT (L) | 2.4 (1.7–3.4) | 3.2 (2.4–4.3)[3] | 4.6 (2.9–6.6) | 4.2 (2.3–6.9) |
| Leg SAT (L) | 3.1 (2.1–4.3) | 4.6 (3.8–6.1)[3] | 6.7 (4.7–9.7) | 9.1 (6.5–11.9)[3] |
| Lower trunk SAT (L) | 3.4 (2.1–5.2) | 5.6 (4.3–7.8)[3] | 7.5 (4.8–11.0) | 9.4 (6.1–12.9)[3] |
| Arm SAT (L) | 1.0 (0.8–1.3) | 1.1 (0.9–1.5)[3] | 1.5 (1.0–2.1) | 2.0 (1.3–2.6)[3] |
| Total fat (L) | 12 (9–17) | 17 (13–23)[3] | 22 (15–32) | 27 (18–36)[3] |
| Total SAT (L) | 10 (7–14) | 15 (12–20)[3] | 21 (14–30) | 26 (17–34)[3] |
| Percentage body fat (%) | 19 (15–24) | 23 (19–28)[3] | 36 (28–43) | 40 (30–46) |
| Metabolic risk indicators | | | | |
| Glucose (mg/dL) | 92 (86–98) | 92 (88–99) | 89 (82–94) | 88 (83–93) |
| Insulin (μU/mL) | 14 (10–20) | 13 (10–18) | 14 (11–20) | 13 (8–19)[3] |
| HOMA | 3.1 (2.1–4.7) | 3.0 (2.2–4.2) | 3.2 (2.4–4.6) | 2.6 (1.8–4.2)[3] |
| TG (mg/dL) | 154 (97–268) | 106 (61–150)[3] | 116 (79–165) | 77 (57–110)[3] |
| HDL (mg/dL) | 40 (33–49) | 47 (39–57)[3] | 50 (40–62) | 54 (46–61)[5] |
| HIV-related factors | | | | |
| Current CD4 (cells/uL) | 336 (206–516) | | 371 (189–557) | |
| HIV RNA (1000/mL) | 0.4 (0.4–13.6) | | 0.8 (0.4–19.7) | |
| HIV duration (y) | 7.4 (5.0–11.7) | | 8.0 (5.6–10.6) | |

[3,5] Test of HIV+ versus control for men and women (Wilcoxon's rank-sum test for continuous variables and Fisher's exact test for categorical variables):

[1] WC, waist circumference; HC, hip circumference; WHR, waist-to-hip ratio; VAT, visceral adipose tissue; SAT, subcutaneous adipose tissue; HOMA, homeostatic model assessment; TG, triglycerides; MRI, magnetic resonance imaging.

[2] Median; interquartile range in parentheses (all such values).

[3] $P < 0.01$

[5] $P < 0.05$.

[4] MRI measures are not height-normalized.

## TABLE 2

Associations of body-composition measures with homeostatic model assessment (HOMA) (log-transformed)[1]

| | Men | | Women | |
|---|---|---|---|---|
| | HIV+ | Control | HIV+ | Control |
| Univariate Spearman correlations (*r*) | | | | |
| MRI | | | | |
| VAT | 0.39[2] | 0.54[2] | 0.28[2] | 0.66[2] |
| UT SAT | 0.40[2] | 0.58[2] | 0.29[2] | 0.64[2] |
| Leg SAT | 0.11[3] | 0.44[2] | 0.10 | 0.41[2] |
| LT SAT | 0.29[2] | 0.62[2] | 0.19[4] | 0.55[2] |
| Arm SAT | 0.26[2] | 0.52[2] | 0.21[4] | 0.56[2] |
| Total SAT | 0.29[2] | 0.59[2] | 0.21[4] | 0.56[2] |
| Total fat | 0.35[2] | 0.61[2] | 0.22[4] | 0.57[2] |
| Percentage body fat | 0.30[2] | 0.56[2] | 0.15[3] | 0.46[2] |
| Anthropometric | | | | |
| BMI | 0.37[2] | 0.58[2] | 0.29[2] | 0.60[2] |
| WC | 0.47[2,5] | 0.64[2,5] | 0.32[2,5] | 0.68[2,5] |
| HC | 0.31[2] | 0.48[2] | 0.19[4] | 0.56[2] |
| WHR | 0.38[2] | 0.48[2] | 0.22[4] | 0.54[2] |
| Multivariate-adjusted $R^2$ | | | | |
| MRI (log-transformed) | | | | |
| VAT | 0.16 | 0.38 | 0.07 | 0.47 |
| VAT + leg SAT | 0.16 | 0.40 | 0.07 | 0.47 |
| VAT + UT SAT + leg SAT | 0.23 | 0.43 | 0.09 | 0.47[5] |
| VAT + UT SAT + LT SAT | 0.21 | 0.44[5] | 0.09 | 0.46 |
| UT SAT + leg SAT | 0.23[5] | 0.40 | 0.09[5] | 0.41 |
| VAT + total SAT | 0.18 | 0.43 | 0.07 | 0.46 |
| Anthropometric | | | | |
| WC | 0.24[5] | 0.46 | 0.09 | 0.45 |
| WC + BMI | 0.24 | 0.48[5] | 0.09 | 0.44 |
| WHR + BMI | 0.22 | 0.46 | 0.11[5] | 0.45[5] |
| Combination | | | | |
| WC + VAT + UT SAT + leg SAT | 0.26[5-8] | 0.45 | 0.10 | 0.47 |
| WC + BMI + VAT + UT SAT + leg SAT | 0.26 | 0.48[5,6] | 0.10 | 0.48 |
| WC + BMI + VAT + UT SAT + LT SAT | 0.25 | 0.48 | 0.14[5,6] | 0.47 |
| WHR + BMI + VAT + leg SAT | 0.22 | 0.47 | 0.11 | 0.48[5,6] |
| Base model[9] | | | | |
| Background variance explained | 0.06 | 0.09 | 0.02 | 0.14 |

[2–4] Significant correlation coefficients

[1] HIV+, HIV-infected; MRI, magnetic resonance imaging; VAT, visceral adipose tissue; UT, upper trunk; LT, lower trunk; WC, waist circumference; WHR, waist-to-hip ratio. All comparisons of best anthropometric versus best MRI had $P > 0.15$. Outcomes were log-transformed to normalize the error residual distribution. For comparison, the models were restricted to have the same set of observations.

[2] $P < 0.0001$

[3] $P < 0.05$

[4] $P < 0.01$.

[5] The strongest MRI, anthropometric, or combination model in each column.

[6] The strongest within the entire column.

[7] Significant comparison with best MRI combination, $P < 0.01$.

[8] Significant comparison with best anthropometric combination, $P < 0.05$.

[9] Base model and all other models were controlled for demographics and lifestyle factors.

## TABLE 3

Associations of body-composition measures with triglycerides (TG) (log-transformed)[1]

| | Men | | Women | |
|---|---|---|---|---|
| | HIV+ | Control | HIV+ | Control |
| Univariate Spearman correlations (*r*) | | | | |
| MRI | | | | |
| VAT | 0.41[2] | 0.42[2,4] | 0.42[2,4] | 0.41[2,4] |
| UT SAT | 0.19[2] | 0.34[2] | 0.26[5] | 0.38[2] |
| Leg SAT | −0.13[6] | 0.12 | −0.03 | 0.08 |
| LT SAT | 0.03 | 0.33[5] | 0.11 | 0.26[6] |
| Arm SAT | 0.07 | 0.24[6] | 0.08 | 0.25[6] |
| Total SAT | 0.03 | 0.29[6] | 0.11 | 0.24[6] |
| Total fat | 0.14[6] | 0.33[5] | 0.13 | 0.26[6] |
| Percentage body fat | 0.13[6] | 0.35[2] | 0.10 | 0.14 |
| Anthropometric | | | | |
| BMI | 0.11[3] | 0.20[3] | 0.17[3] | 0.32[5] |
| WC | 0.32[2] | 0.32[5] | 0.30[2] | 0.39[2] |
| HC | 0.03 | 0.13 | 0.08 | 0.29[6] |
| WHR | 0.44[2,4] | 0.41[2] | 0.39[2] | 0.37[2] |
| Multivariate-adjusted $R^2$ | | | | |
| MRI (log-transformed) | | | | |
| VAT | 0.17 | 0.17 | 0.19 | 0.12 |
| UT + leg SAT | 0.16 | 0.16 | 0.17 | 0.16[4] |
| VAT + UT SAT + leg SAT | 0.21[4] | 0.18[4,7] | 0.21[4] | 0.16 |
| VAT + total SAT | 0.20 | 0.16 | 0.20 | 0.11 |
| Anthropometric | | | | |
| WHR | 0.21 | 0.15 | 0.20 | 0.15 |
| WC + BMI | 0.19 | 0.15[4] | 0.19 | 0.15 |
| WHR + BMI | 0.21[4] | 0.15 | 0.20[4] | 0.18 |
| HC + BMI | 0.11 | 0.09 | 0.15 | 0.22[4] |
| Combination | | | | |
| WHR + BMI + VAT + leg SAT | 0.24[4,7-10] | 0.17 | 0.25 | 0.27 |
| WHR + UT SAT | 0.21 | 0.18[4] | 0.22 | 0.15 |
| WC + BMI + VAT + leg SAT | 0.23 | 0.17 | 0.24 | 0.27[4,7] |
| WHR + VAT | 0.22 | 0.18 | 0.26[4,7,10,9] | 0.15 |
| Base model[11] | | | | |
| Background variance explained | 0.09 | 0.05 | 0.06 | 0.03 |

[2,4–6] Significant correlation coefficients

[8,10] Significant comparison with best MRI combination

[1] HIV+, HIV-infected; MRI, magnetic resonance imaging; VAT, visceral adipose tissue; UT, upper trunk; LT, lower trunk; WC, waist circumference; WHR, waist-to-hip ratio. All comparisons of best anthropometric versus best MRI had $P > 0.15$. Outcomes were log-transformed to normalize the error residual distribution. For comparison, the models were restricted to have the same set of observations.

[2] $P < 0.0001$

[4] $P < 0.001$

[5] $P < 0.01$

[6] $P < 0.05$.

[3] The strongest MRI, anthropometric, or combination model in each column.

[7] The strongest within the entire column.

[8] $P < 0.01$

[10] $P < 0.05$.

[9] Significant comparison with best anthropometric combination, $P < 0.01$.

[11] Base model and all other models were controlled for demographics and lifestyle factors.

## TABLE 4

Associations of body-composition measures with HDL (log-transformed)[1]

| | Men | | Women | |
|---|---|---|---|---|
| | HIV+ | Control | HIV+ | Control |
| Univariate Spearman correlations (*r*) | | | | |
| MRI | | | | |
| VAT | −0.26[2,4] | −0.36[2,4] | −0.19[4,5] | −0.43[2] |
| UT SAT | −0.10[6] | −0.31[3] | −0.12 | −0.41[2] |
| Leg SAT | +0.06 | −0.17 | −0.02 | −0.27[5] |
| LT SAT | −0.04 | −0.34[2] | −0.05 | −0.38[2] |
| Arm SAT | −0.04 | −0.26[5] | −0.08 | −0.37[2] |
| Total SAT | −0.03 | −0.30[3] | −0.06 | −0.38[2] |
| Total fat | −0.09[6] | −0.33[3] | −0.07 | −0.40[2] |
| Percentage body fat | −0.06 | −0.34[2] | −0.04 | −0.27[5] |
| Anthropometric | | | | |
| BMI | −0.12[5] | −0.22[6] | −0.11 | −0.40[2] |
| WC | −0.23[2] | −0.30[3] | −0.16[6] | −0.48[2,4] |
| HC | −0.12[6] | −0.23[5] | −0.06 | −0.42[2] |
| WHR | −0.23[2] | −0.24[5] | −0.18[6] | −0.28[5] |
| Multivariate-adjusted $R^2$ | | | | |
| MRI (log-transformed) | | | | |
| VAT | 0.15 | 0.27 | 0.08 | 0.21[4] |
| Leg SAT | 0.13 | 0.26 | 0.10 | 0.17 |
| LT SAT | 0.13 | 0.30[4,7] | 0.06 | 0.20 |
| VAT + leg SAT | 0.16[4] | 0.28 | 0.11[4] | 0.20 |
| VAT + total SAT | 0.16 | 0.29 | 0.10 | 0.20 |
| Anthropometric | | | | |
| WC | 0.16 | 0.29 | 0.09 | 0.24[4,7] |
| HC | 0.13 | 0.29[4] | 0.06 | 0.22 |
| WC + BMI | 0.16[4] | 0.28 | 0.10 | 0.24 |
| % Fat | 0.12 | 0.27 | 0.11[4] | 0.21 |
| Combination | | | | |
| WC + BMI + VAT + leg SAT | 0.17 | 0.28 | 0.17 | 0.23 |
| HC + LT SAT | 0.14 | 0.30[4] | 0.06 | 0.23 |
| WC + BMI + VAT + UT + leg SAT | 0.18[4,7] | 0.28 | 0.17[4,7,8] | 0.23 |
| WC + UT SAT | 0.17 | 0.29 | 0.10 | 0.24[4] |
| Base model[9] | | | | |
| Background variance explained | 0.12 | 0.19 | 0.06 | 0.09 |

[2,4–6] Significant correlation coefficients

[1] HIV+, HIV-infected; MRI, magnetic resonance imaging; VAT, visceral adipose tissue; UT, upper trunk; LT, lower trunk; WC, waist circumference; WHR, waist-to-hip ratio. All comparisons of best anthropometric versus best MRI had $P > 0.15$. Outcomes were log-transformed to normalize the error residual distribution. For comparison, the models were restricted to have the same set of observations.

[2] $P < 0.0001$

[4] $P < 0.01$

[5] $P < 0.05$

[6] $P < 0.001$.

[3] The strongest MRI, anthropometric, or combination model in each column.

[7] The strongest within the entire column.

[8] Significant comparison of best MRI with best combination of MRI and anthropometrics, $P < 0.05$.

[9] Base model and all other models were controlled for demographics and lifestyle factors.

**TABLE 5**

Comparison of best-fitting models with waist circumference (WC), waist-to-hip ratio (WHR), or visceral adipose tissue (VAT) alone[1]

| Sex and comparison | Best model | Metabolic outcome | | | | | |
|---|---|---|---|---|---|---|---|
| | | HIV+ | | | Control | | |
| | | HOMA | TG | HDL | HOMA | TG | HDL |
| | | | $\Delta R^2$ | | | $\Delta R^2$ | |
| Men | | | | | | | |
| WC | MRI | −0.010[2] | 0.065[3] | 0.006 | −0.028 | 0.030 | 0.012 |
| | Anthropometric | —[5] | 0.070[6] | 0.000 | 0.016 | 0.003 | 0.004 |
| | Combination | 0.023[7] | 0.100[4] | 0.024 | 0.020 | 0.030 | 0.011 |
| WHR | MRI | 0.053 | −0.004 | 0.011 | 0.126 | 0.028 | 0.084[3] |
| | Anthropometric | 0.064[3] | 0.001 | 0.005 | 0.169[3] | 0.001 | 0.075[7] |
| | Combination | 0.086[4] | 0.031[3] | 0.029 | 0.173[3] | 0.028 | 0.083[3] |
| VAT | MRI | 0.070[3] | 0.035[3] | 0.016 | 0.052[7] | 0.013 | 0.023 |
| | Anthropometric | 0.081[6] | 0.040 | 0.010 | 0.095[7] | −0.014 | 0.015 |
| | Combination | 0.104[4] | 0.070[4] | 0.034[7] | 0.099[7] | 0.013 | 0.023 |
| Women | | | | | | | |
| WC | MRI | −0.003 | 0.061 | 0.017 | 0.025 | 0.007 | −0.032 |
| | Anthropometric | 0.021 | 0.051 | 0.020 | 0.000 | 0.069 | — |
| | Combination | 0.049 | 0.102[3] | 0.084 | 0.038 | 0.115[4] | −0.005 |
| WHR | MRI | −0.008 | 0.011 | 0.017 | 0.160[3] | 0.014 | 0.032 |
| | Anthropometric | 0.015 | 0.002 | 0.021 | 0.135[4] | 0.076 | 0.065[7] |
| | Combination | 0.044 | 0.053[3] | 0.084[7] | 0.173[4] | 0.122 | 0.060 |
| VAT | MRI | 0.019 | 0.020 | 0.030 | 0.004 | 0.044 | — |
| | Anthropometric | 0.042 | 0.011 | 0.033 | −0.020 | 0.106[3] | 0.032 |
| | Combination | 0.071[7] | 0.062[3] | 0.097[7] | 0.017 | 0.152[4] | 0.027 |

[3,5–7] Significant comparison of adjusted $R^2$ between models:

[1] HOMA, homeostatic model assessment; TG, triglycerides; MRI, magnetic resonance imaging. Comparisons are differences in adjusted $R^2$ values based on models presented in Tables 2-4.

[2] A negative $\Delta R^2$ indicates a larger $R^2$ for the comparison model than for the best model.

[3] $P < 0.01$,

[5] $P < 0.001$,

[6] $P < 0.05$,

[7] $P < 0.0001$.

[4] Best model and comparison model are the same in that category.