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Nutrition in Health and Disease

Diet Quality and Visceral Adiposity among a Multiethnic Population of Young, Middle, and Older Aged Adults

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ABSTRACT

Background: Visceral adiposity, more so than overall adiposity, is associated with chronic disease and mortality. There has been, to our knowledge, little research exploring the association between diet quality and visceral adipose tissue (VAT) among a mulitethnic population aged 18–80 y.

Objective: The primary objective of this cross-sectional analysis was to examine the association between diet quality [Healthy Eating Index–2010 (HEI-2010) scores] and VAT among a multiethnic population of young, middle, and older aged adults in the United States. Secondary objectives were to repeat these analyses with overall adiposity and blood-based biomarkers for type 2 diabetes and cardiovascular disease risk as outcome measures.

Methods: A total of 540 adults (dropped out: $n = 4$; age: 18–40 y, $n = 220$; 40–60 y, $n = 183$; 60–80 y, $n = 133$) were recruited across 3 sites (Honolulu County, San Francisco, and Baton Rouge) for the Shape Up! Adults study. Whole-body DXA, anthropometry, fasting blood draw, and questionnaires (food frequency, physical activity, and demographic characteristics) were completed. Linear regression was used to assess the associations between HEI-2010 tertiles and VAT and secondary outcome measures among all participants and age-specific strata, while adjusting for known confounders.

Results: VAT, BMI (kg/m^2), body fat percentage, total body fat, trunk fat, insulin, and insulin resistance were inversely related to diet quality (all P values < 0.004). When stratified by age, diet quality was inversely associated with VAT among participants aged 60–80 y ($P < 0.006$) and VAT/subcutaneous adipose tissue (SAT) among participants aged 40–60 y ($P < 0.008$).

Conclusions: Higher-quality diet was associated with lower VAT, overall adiposity, and insulin resistance among this multiethnic population of young, middle, and older aged adults with ages ranging from 18 to 80 y. More specifically, adherence to a high-quality diet may minimize VAT accumulation in adults aged 60–80 y and preferentially promote storage of SAT compared with VAT in adults aged 40–60 y. This study was registered at clinicaltrials.gov as NCT03637855. *Curr Dev Nutr* 2020;4:nzaa090.

Keywords: Diet quality, Healthy Eating Index, visceral adipose tissue, obesity, multiethnic, DXA, young adults, middle aged adults, older adults

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Abbreviations used: DGC, Dietary Guidelines Advisory Committee; DHQ II, Diet History Questionnaire II; GLM, general linear model; GSLTPAQ, Godin-Shephard leisure-time physical activity questionnaire; HbA1c, glycated hemoglobin; HC, hip circumference; HEI-2010, Healthy Eating Index-2010; IRB, institutional review board; MEC-APS, Multiethnic Cohort Adiposity Phenotype Study; NHOPI, Native Hawaiian or Other Pacific Islander;NCI, National Cancer Institute; PBRC, Pennington Biomedical Research Center; REDCap, Research Electronic Data Capture; SAT, subcutaneous adipose tissue; UCSF, University of California San Francisco; UHCC, University of Hawaii Cancer Center; VAT, visceral adipose tissue; VAT/SAT, visceral adipose tissue/ subcutaneous adipose tissue ratio; WC, waist circumference; WHR, waist-hip ratio.

Introduction

Excessive abdominal adiposity is known to be more harmful than lower body adiposity (1–4). In particular, higher amounts of visceral adiposity are associated with greater risk of cardiovascular disease (CVD) (3, 5), type 2 diabetes (6, 7), certain cancers (8–10), and mortality (11–13). Determinants of visceral adipose tissue (VAT) include age (2, 4, 14), sex (1, 2, 4), physical activity (4, 15), ethnicity (2, 4), alcohol intake (16), and diet (4, 17–19).

With advancing age, VAT increases in both men and women across racial and ethnic groups (14). Racial and ethnic heterogeneity have been found to influence the propensity for VAT storage over subcutaneous adipose tissue (SAT) (20, 21). In the MEC-APS (Multiethnic Cohort Adiposity Phenotype Study), relative to total body fat,

VAT was highest in Japanese Americans, lowest in blacks and African Americans, and intermediate in Native Hawaiians, Hispanic, Latino, and white people (21). For the effect of diet on VAT, researchers have reported that higher intakes of medium-chain triglycerides, dietary fiber, calcium, and/or phytochemicals may be associated with lower amounts of VAT, and following a high-quality dietary pattern is inversely related to VAT (17, 18, 22, 23). Among 1861 participants aged 58–74 y in the MEC-APS study, results demonstrated that adherence to a high-quality diet [e.g., higher Healthy Eating Index-2010 (HEI-2010) score] was associated with lower adiposity, in particular VAT (18).

Studying the effects of individual foods on health is important; however, analyses of the whole diet capture the synergistic effects of nutrients on health outcomes (24). Previous research assessing the relationship between diet quality and VAT for adults has been performed in study populations within a limited age range (18, 22, 23), and participants have been predominantly white (17, 22). To our knowledge, only the MEC-APS study has explored the association between VAT and diet quality across a multiethnic group of older adults (18). Further research is needed to examine the effect of diet quality on VAT among a multiethnic population across adulthood. Given that there are no official clinical guidelines for the prevention and treatment of VAT, such research may help to inform and tailor interventions targeting loss of VAT.

The primary aim of this cross-sectional analysis was to examine the association between diet quality as defined by the HEI-2010 score and DXA-based VAT among a multiethnic population of young, middle, and older aged adults in the United States. Secondary objectives were to repeat these analyses with overall adiposity and blood-based biomarkers of type 2 diabetes and cardiovascular disease risk as outcome measures.

Methods

Study population

Shape Up! Adults (NIH R01 DK109008) is a cross-sectional study with a primary aim of identifying the association between body shape and body composition indices among the US population. Shape Up! Adults intends to recruit 720 adults (age 18–80 y) within predetermined strata by sex, age (18–40, 40–60, and 60–80 y), BMI (<18.5, 18.5–24.9, 25–29.9, and ≥30 kg/m^2), race/ethnicity [non-Hispanic white, black or African American, Hispanic or Latino, Asian, and Native Hawaiian or Other Pacific Islander (NHOPI)], and geographic location (San Francisco, CA; Baton Rouge, LA; or Honolulu County, HI). The Shape Up! Adults study began in October 2016 and the estimated completion date is September 2020. Available data used for the current analysis were from 540 study participants (75% of the anticipated study sample) .

Participants were recruited by convenience sampling (25) at 3 sites, the Pennington Biomedical Research Center (PBRC) (n = 311), University of California San Francisco (UCSF) (n = 173), and University of Hawaii Cancer Center (UHCC) (n = 56), via flyers, news broadcasts, health fairs, and word of mouth. Individuals eligible to participate were ambulatory and met the study strata requirements. Exclusion criteria for the current study, which were based on the primary aims of the Shape Up! Adults study, included being unable to lie flat without moving for 10 min or stand without aid for 2 min; having missing limbs or nonremovable metal in the body (e.g., joint replacements), or a history of body-altering surgery (e.g., liposuction), and in women, being pregnant or breastfeeding (26). Those screened as eligible over the telephone were scheduled for a clinic visit. A total of 6943 people responded to the study promotions. Of these, 6403 people were excluded because they did not meet the eligibility criteria, the study strata was full, or they refused to participate (**Figure 1**).

Study measurements

Study preparations included fasting for at least 8 h (water and prescription medication were allowed). Participants self-reported whether they had fasted before the clinic visit. Anthropometric measures, whole-body DXA, and a fasting blood draw were performed, and a characteristics questionnaire was administered by trained staff in the clinic at each site. A self-administered FFQ and the Godin-Shephard leisure-time physical activity questionnaire (GSLTPAQ) were completed at the clinic (n = 524) or at home (n = 16). As reimbursement for time and travel, each participant received a $50 gift card. Participants were provided with their whole-body DXA, BMI, and blood biochemistry panel results and encouraged to contact their primary care physician if any test results were outside the recommended range. All participants provided informed consent, and the study protocol was approved by the institutional review boards (IRBs) at PBRC (PBRC, IRB study no. 2017–10, FWA no. 00006218), UCSF (UCSF, IRB no. 16-20,197), and the University of Hawaii Office of Research Compliance (UH ORC, CHS no. 24282).

Dietary intake

Dietary data were collected using the standard format of the Diet History Questionnaire II (DHQ II) version 2.0 [NIH, Epidemiology and Genomics Research Program, National Cancer Institute (NCI), 2010]. The DHQ II is a semi-quantitative FFQ consisting of 134 food items and 8 dietary supplement questions to capture intake in the past year and typical portion sizes (27, 28). Software developed by the NCI Epidemiology and Genomics Research Program (Diet∗Calc Analysis Program, version 1.5.0, October 2012) allows analysis of DHQ II data (27) and is linked with the DHQ II Nutrient Database (dhq2.database.092914.csv), which comprises information from the USDA Food and Nutrient Database for Dietary Studies, the USDA MyPyramid Equivalents Database, and the Nutrition Data System for Research (NDS-R) (29–31). Study staff transferred the DHQ II into REDCap (Research Electronic Data Capture), a secure web-based application for building and managing online surveys and databases, and participants completed the DHQ II online. Participants were instructed to ask study staff for assistance with the DHQ II if needed. For the small number of participants who preferred to complete the DHQ II at home, instructions were emailed on how to access and complete the DHQ II remotely. Once completed, data were downloaded from REDCap and analyzed using the Diet∗Calc program for computation of total energy, nutrients, bioactive components, and food groups. The Diet∗Calc results file and SAS code, available through NCI (32), were used to calculate HEI-2010 total scores.

The HEI-2010 is a diet quality index and measures compliance to the 2010 Dietary Guidelines for Americans (33). Higher HEI-2010 scores reflect greater adherence to these dietary guidelines (33). The

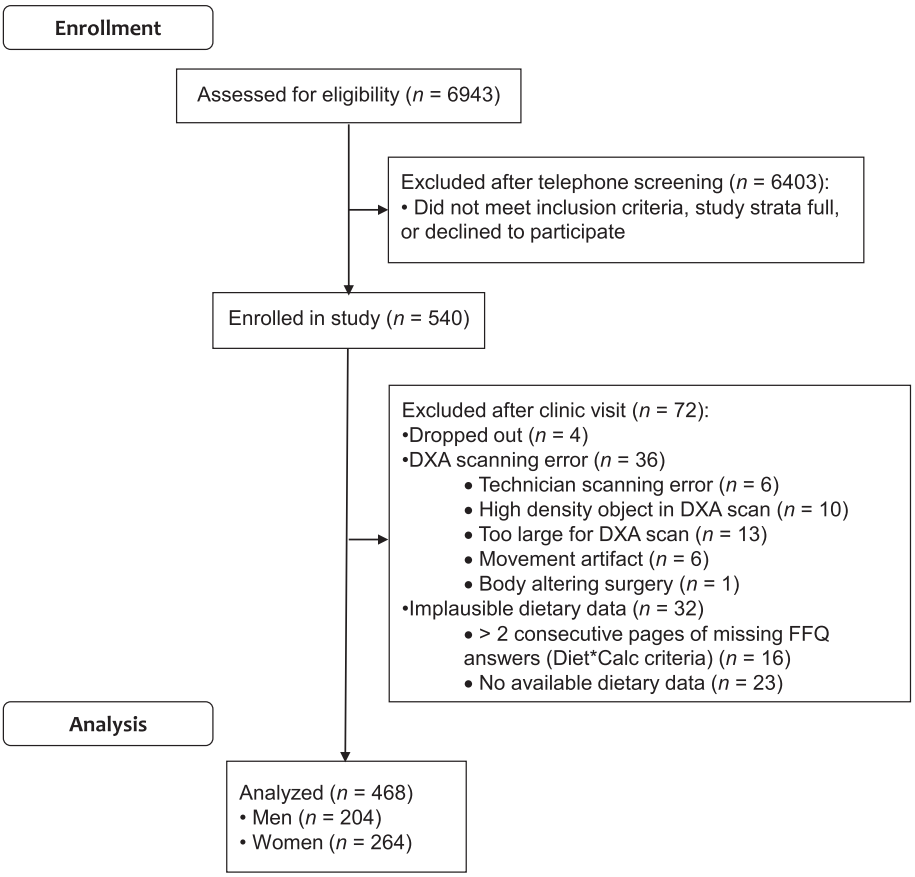

FIGURE 1 Flow diagram for the Shape Up! Adults study (NIH RO1DK109008) as of this publication.

HEI-2010 scoring system is a 100-point scale comprising 12 components worth 5–20 points each, including 9 adequacy components (foods to eat enough of) and 3 moderation components (foods to limit) (33). Adequacy components include total fruit, whole fruit, total vegetables, greens, beans, whole grains, dairy, total protein foods, seafood and plant proteins, and fatty acids (33). Moderation components include refined grains, sodium, and empty calories (kcal from solid fats, alcohol, and added sugars) (33). The scoring system primarily uses a density based approach (i.e., per 1000 kcal), except for 2 components: ≤19% of kcal is used for the Empty Calories component, and for the Fatty Acids component a specified ratio is used for poly- and monounsaturated fatty acids to saturated fatty acids. Collectively these specified scoring mechanisms across the components allow common scoring standards to be used (34).

Physical activity and characteristics questionnaires

The GSLTPAQ was used to collect data on amounts of participant physical activity (35). Questions from the GSLTPAQ were added to the end of the online REDCap DHQ II. Briefly, the GSLPAQ consists of 3 questions, and asks, in a typical week, how many times >15 min of strenuous, moderate, and mid/light exercise is performed (35). Physical activity amount (insufficiently active and active) was calculated using data from the GSLTPAQ, according to a standard protocol (35). Briefly, answers to questions on strenuous and moderate exercise were multiplied by 9 and 5, respectively, and added together to obtain a total score. In order to compute a score corresponding to health contribution, the total score was split into 2 groups, with scores of ≤23 representing insufficiently active and ≥24 denoting active (35).

A characteristic questionnaire was used to collect data on sex, age, and ethnicity. Participants who identified as having ancestries of multiple ethnic origins selected the ethnicity with which they identified the most.

DXA measures

DXA and anthropometric measures were collected using an adaptation of the protocol described by Ng et al. (26). In the current study, each participant underwent 2 whole-body DXA scans with repositioning on either a Hologic Horizon/A system at UCSF or a Hologic Discovery/A system at PBRC and at UHCC (Hologic Inc.). Results of the 2 whole-body DXA scans were averaged. Participants were scanned according to the manufacturer's guidelines. All DXA scans were centrally analyzed at UHCC by a single certified technologist using Hologic Apex 5.5 software. Output from DXA included regional and whole-body percentage fat mass, lean soft tissue mass, and mean VAT and SAT for L1–L5. DXA cross-calibration phantoms were circulated between all sites, and calibration equations were derived to remove systematic bias in all bone and soft tissue results.

Anthropometry

Trained technicians obtained measurements of height, weight, waist circumference (WC), and hip circumference (HC), according to a standard protocol from the NHANES (36). Three weight and height measurements were collected using a calibrated scale and stadiometer, and the results were averaged. Triplicate circumference measurements were collected to the nearest 0.1 cm, using a flexible measuring tape, and the results were averaged. If a measurement differed by >1 cm, a fourth measurement was taken and the closest 3 measurements averaged. BMI (kg/m^2) was calculated, and waist to hip ratio was calculated as WC divided by HC.

Blood serum biomarkers

A whole-blood fasting sample of 40 mL was collected from each participant. Blood samples were placed on ice and processed within 4 h into plasma, serum, whole blood, and buffy coat components, following which they were stored at −80°C at each study site until analysis. Complete blood counts were analyzed at the respective clinic sites. Biochemical analyses of all lipid and blood chemistry profiles were performed at PBRC. Serum chemistry panels were assayed through the use of a DXC600 instrument (Beckman Coulter, Inc.). Insulin was measured by immunoassay on an Immulite 2000 platform (Siemens Corporation). Measurements of fasting glucose, glycated hemoglobin (HbA1c), insulin, HOMA-IR, alanine transaminase (ALT), total cholesterol, HDL and LDL cholesterol, and serum triglycerides were used in the current analysis.

Statistical methods

Of the 540 study participants, analyses were limited to the 468 participants (men, $n = 204$; women, $n = 264$) who completed the study (excluding $n = 4$) and for whom data for accurate DXA scans (excluding $n = 36$), and plausible dietary assessment information (excluding $n = 32$) (Figure 1). DXA scanning errors occurred as a result of technician scanning errors, a high-density object in the DXA scan, too large for DXA scan, movement artifact, and body altering surgery (Figure 1). Implausible dietary data were flagged by Diet∗Calc when >2 consecutive pages of FFQ data were missing.

Diet quality was scored using the HEI-2010, and total scores were divided into tertiles, with the highest tertile (T3) representing the highest diet quality and the lowest tertile (T1) the lowest diet quality (18). Forty-nine participants had missing physical activity data and were included in analyses in a missing category.

For analysis of the primary outcome, a general linear model (GLM) was used to estimate covariate-adjusted mean values for DXA-based VAT by HEI-2010 tertiles (18). Linear trends were estimated to assess dose–response relations of VAT across HEI-2010 tertiles. The same approach was applied to analyze the data stratified by age groups (18–40, 40–60, and 60–80 y), sex, and race/ethnicity [white, black or African American, Asian, or other, including Native Hawaiian or Other Pacific Islander (NHOPI) and Hispanic or Latino], to assess if associations seen in the whole sample were present within subgroups. Linear trends were also examined to assess dose–response relations in VAT between age groups (18–40, 40–60, 60–80 y) within each HEI-2010 tertile, using a nominal trend variable for age groups. All models for VAT were adjusted for age, total body fat, and total energy intake (log-transformed) as continuous variables, and sex, ethnicity, physical activity level (insufficiently active, active, and missing), and alcohol (<14 or ≥14 g/d of ethanol) as categorical variables (18).

Secondary analyses explored relationships between diet quality and anthropometric measures [BMI, WC, HC, and waist-hip ratio (WHR)], DXA-based measures (body fat percentage, total body fat, lean mass, SAT, VAT/SAT, and trunk fat), and blood-based biomarkers for type 2 diabetes and CVD risk (total cholesterol, HDL, LDL, triglycerides, glucose, insulin, HbA1c, and ALT) applying the same methods as the GLM above. Most models were adjusted for total body fat, with the exception of models for BMI, total body fat, or body fat percentage. Among the final study sample ($n = 468$), participants with a missing blood or anthropometric measure were removed from the analysis for that outcome measure, and added back into the dataset for remaining analyses.

Mean ± SD HEI-2010 component scores were computed, and stratified by age groups. Additional analyses assessed the independent association between HEI-2010 components and VAT, for each component (component *i*), adjusting for age, total body fat, total energy intake, sex, ethnicity, physical activity level, alcohol intake, and a modified total HEI-2010 score, which did not include the respective HEI-2010 component (modified total HEI-2010 score = total HEI-2010 score – HEI-2010 component *i*).

For all analyses, statistical significance was defined as $P < 0.05$. Data were analyzed using IBM SPSS Statistics version 25 software (IBM Corp.).

Results

Due to the stratified recruitment, the study sample contained almost an equal number of men (43.6%) and women (56.4%) (**Table 1**), with a mean age of 45.6 ± 16.6 y. The distribution of participants in the age groups 18–40, 40–60, and 60–80 y, was 41.9%, 32.3%, and 25.9%, respectively, with the number of participants in the 18–40-y category being significantly higher than the number in the other 2 age categories. Overall, 39.1% of participants identified as predominately white, 26.9% as black or African American, 23.3% as Asian, and 10.7% as Hispanic or Latino or NHOPI (Hispanic or Latino and NHOPI were recoded as "Other"). Between age strata, there was a fairly even distribution of participants from each racial/ethnic group, except for the Other category, for which the proportion of participants 60–80 y of age, was significantly lower than the proportion for all other age categories.

The mean HEI-2010 score was 67.2 ± 11.5 (range 28.9–90.3) with participants aged 60–80 y having significantly higher diet quality and participants aged 18–40 y scoring the lowest for diet quality. Consequently, the largest proportion of participants in HEI-2010 T3 (highest diet quality) were participants aged 60–80 y, and the largest proportion of participants in T1 (lowest diet quality) were those aged 18–40 y. Older age was significantly associated with higher HEI-2010 component scores for total fruit, whole fruit, whole grains, seafood and plant proteins, fatty acids, refined grains, and sodium (**Supplemental Table 1**). For the whole study sample, mean VAT was 481.4 ± 305.0 cm^3, and between age group strata, participants aged 60–80 y had significantly higher VAT than participants aged 18–40 y. For the study sample and for participants aged 60–80 y, VAT was inversely related to diet quality with a significant trend across tertiles (**Table 2**). Looking across age

TABLE 1 Descriptive characteristics of participants ($n = 468$) in the Shape Up! Adults Study by age groups[1]

Characteristic	All	Age Group		
		18–40 y	40–60 y	60–80 y
n (%)[2]	468 (100)	196 (41.9)	151 (32.3)	121 (25.9)
Age, y[3,4,5]	45.6 ± 16.6	28.7 ± 6.2	50.9 ± 6.2	66.5 ± 4.2
Energy, kcal[4]	1702 (1237–2452)	1838 (1359–2803)	1717 (1210–2545)	1609 (1005–1963)
VAT, cm[3,4]	481.4 ± 305.0	326.6 ± 198.3	570.0 ± 325.0	621.8 ± 311.8
HEI-2010[4,5]	67.2 ± 11.5	64.9 ± 10.3	66.9 ± 11.5	71.1 ± 12.1
HEI-2010, range	28.9–90.3	30.6–88.8	28.9–86.2	32.4–90.3
HEI-2010 tertile				
Tertile 1[2]	156 (33.3)	80 (40.8)	44 (29.1)	32 (26.5)
Tertile 2[2,6]	156 (33.3)	75 (38.3)	58 (38.4)	23 (19.0)
Tertile 3[2,6,7]	156 (33.3)	41 (20.9)	49 (32.5)	66 (54.5)
Sex				
Male	204 (43.6)	92 (46.9)	60 (39.7)	52 (43.6)
Females	264 (56.4)	104 (53.1)	91 (60.3)	69 (56.4)
Ethnicity				
White	183 (39.1)	71 (36.2)	57 (37.7)	55 (45.5)
Black or African American	126 (26.9)	49 (25.0)	42 (27.8)	35 (28.9)
Asian	109 (23.3)	46 (23.5)	35 (23.2)	28 (23.1)
Other[6,7]	50 (10.7)	30 (15.3)	17 (11.3)	3 (2.5)
BMI, kg/m^2				
Mean	27.2 ± 7.8	26.7 ± 6.3	28.3 ± 10.5	26.4 ± 5.6
<25	194 (41.5)	80 (40.8)	60 (39.7)	54 (44.6)
25 < 30	154 (32.9)	69 (35.2)	45 (29.8)	40 (33.1)
≥30	120 (25.6)	47 (24.0)	46 (30.5)	27 (22.3)
Physical activity level				
Insufficiently active[2]	148 (32)	49 (25)	52 (34)	47 (39)
Active[6,7]	271 (58)	135 (69)	80 (53)	56 (46)
Missing[7]	49 (10)	12 (6)	19 (13)	18 (15)

[1]Values represent numbers (percentages) of participants, means ± SDs, or medians (IQRs) unless otherwise indicated. HEI-2010, Healthy Eating Index-2010; VAT, visceral adipose tissue.
[2]Significant difference by test of proportions: 18–40 y vs. 60–80 y.
[3]Significant difference by analysis of variance (ANOVA): 18–40 y vs. 40–60 y.
[4]Significant difference by ANOVA: 18–40 y vs. 60–80 y.
[5]Significant difference by ANOVA: 40–60 y vs. 60–80 y.
[6]Significant difference by test of proportions: 18–40 y vs. 40–60 y.
[7]Significant difference by test of proportions: 40–60 y vs. 60–80 y.

groups, for each HEI-2010 tertile (T), there was a significant positive trend between age and VAT (Table 2).

For the per HEI component analysis (**Supplemental Table 2**) for all age groups, no single HEI component was significantly associated with VAT. For analyses of HEI-2010 and VAT, stratified by race/ethnicity, white participants in T3 had significantly lower VAT than those in T1, with a significant trend (**Supplemental Tables 3–4**). For Asian participants, VAT was significantly lower in T3 compared with T2, and the trend was close to significance ($P = 0.058$). For the black or African American and the Other race/ethnicity groups, those with the highest diet quality scores appeared to have the lowest VAT; however, these differences were not significant. In the analyses of HEI-2010 and VAT stratified by sex, a significant inverse relationship between diet quality and VAT was seen in men and women (**Supplemental Tables 6** and 7).

For the study sample, BMI, body fat percentage, total body fat, and trunk fat were inversely related to diet quality with a significant trend across tertiles (Table 2). For participants aged 18–40 y, BMI, body fat percentage, total body fat, SAT, and trunk fat were inversely related to diet quality with a significant trend across tertiles. Unique to participants aged 40–60 y, VAT/SAT was inversely related to diet quality, with a significant trend across tertiles. For participants aged 60–80 y, BMI, body fat percentage, and total body fat were inversely related to diet quality with a significant trend across tertiles. Looking across age groups, among those with the highest diet quality, participants aged 18–40 y had significantly lower WC, WHR, body fat percentage, VAT/SAT, and trunk fat (Table 2) compared to participant aged s 60–80 y with a significant trend. Among T3, for participants aged 18–40 y, HC and lean mass were significantly higher than those in participants aged 60–80 y, with a significant trend across age groups. These patterns were similar among participants in T2 and T1, with the exception of body fat percentage for participants in T2, which did not significantly differ across age groups.

For blood-based biomarkers (**Table 3**) of type 2 diabetes and CVD risk, among the total study sample and within the 18–40 y and 40–60 y age groups, higher diet quality was inversely related to insulin and insulin resistance, with a significant trend across tertiles. Unique to participants aged 18–40 y were the significantly lower triglycerides for T3 compared to T1, with a significant trend.

Exploring the racial/ethnic-specific association of diet quality, overall adiposity, and blood-based biomarkers of diabetes and CVD risk,

TABLE 2 Adjusted means (95% CIs) for body measurements by Healthy Eating Index-2010 tertiles and age groups[1]

HEI-2010 tertiles	*n*	All, mean (*n* = 468)	*n*	18–40 y (*n* = 196)	*n*	40–60 y (*n* = 151)	*n*	60–80 y (*n* = 121)	*P*-trend[2]
BMI, kg/m^2									
T1	155	27.5 (26.0, 29.0)	80	26.4 (24.5, 28.2)	44	28.9 (24.6, 33.1)	32	28.3 (25.5, 31.1)	0.21
T2	156	27.6 (26.0, 29.0)	75	26.2 (24.4, 28.0)	58	29.8 (26.1, 33.5)	23	25.6 (22.7, 28.6)	0.55
T3	156	24.6 (23.0, 26.2)	41	23.9 (21.4, 26.5)	49	24.8 (20.9, 28.6)	66	25.0 (22.6, 27.4)	0.92
P-trend[3]		0.002[4,5]		0.049[5]		0.11[4]		0.010[5]	
WC, cm[6]									
T1	153	93.1 (91.9, 94.4)	79	88.6 (86.9, 90.3)	43	98.2 (95.5, 100.9)	31	94.8 (91.3, 98.3)	0.048[7]
T2	154	92.4 (91.2, 93.6)	73	88.8 (87.1, 90.5)	58	95.1 (92.7, 97.4)	23	95.2 (91.4, 98.9)	0.028[7]
T3	153	92.6 (91.3, 94.0)	39	88.6 (86.2, 91.0)	49	96.8 (94.4, 99.3)	65	94.4 (91.3, 97.6)	0.039[7]
P-trend		0.54				0.40		0.83	
HC, cm[6]									
T1	153	102.4 (101.4, 103.4)	79	101.8 (100.2, 103.4)	43	105.2 (103.3, 107.1)	31	100.8 (98.4, 103.1)	0.011[7]
T2	154	102.5 (101.6, 103.5)	73	101.7 (100.0, 103.3)	58	105.1 (103.5, 106.8)	23	101.8 (99.3, 104.3)	0.020[7]
T3	153	103.0 (101.9, 104.1)	39	102.3 (100.0, 104.5)	49	104.9 (103.2, 106.6)	65	102.2 (100.1, 104.2)	<0.001[7,8]
P-trend		0.31		0.64		0.77		0.21	
WHR[6]									
T1	153	0.91 (0.90, 0.92)	79	0.87 (0.85, 0.89)	43	0.93 (0.91, 0.96)	31	0.94 (0.90, 0.98)	0.001[7]
T2	154	0.90 (0.89, 0.92)	73	0.88 (0.86, 0.90)	58	0.91 (0.88, 0.93)	23	0.94 (0.90, 0.98)	0.020[7]
T3	153	0.90 (0.88, 0.91)	39	0.87 (0.84, 0.89)	49	0.92 (0.89, 0.95)	65	0.93 (0.89, 0.96)	<0.001[7]
P-trend		0.13		0.84		0.44		0.42	
Body fat, %									
T1	155	29.1 (27.8, 30.4)	80	26.9 (24.9, 28.9)	44	29.3 (26.7, 32.0)	32	31.5 (28.1, 34.9)	0.002[7]
T2	156	28.5 (27.2, 29.8)	75	25.6 (23.6, 27.6)	58	31.3 (28.9, 33.6)	23	27.7 (24.1, 31.4)	0.09
T3	156	25.9 (24.5, 27.3)	41	23.3 (20.7, 26.0)	49	26.7 (24.3, 29.1)	66	27.6 (24.6, 30.6)	0.013[7]
P-trend		<0.001[4,5]		0.008[5]		0.10[4]		0.014[5]	
Total body fat, kg									
T1	155	22.9 (20.9, 24.9)	80	20.1 (17.1, 23.1)	44	24.3 (19.9, 28.7)	32	24.6 (19.9, 29.3)	0.08
T2	156	22.1 (20.1, 24.0)	75	19.1 (16.1, 22.1)	58	25.6 (21.8, 29.4)	23	19.6 (14.6, 24.6)	0.98
T3	156	18.4 (16.3, 20.6)	41	15.8 (11.7, 19.9)	49	20.1 (16.1, 24.0)	66	19.1 (14.9, 23.2)	0.32
P-trend		<0.001[4,5]		0.033[5]		0.11[4]		0.011[5]	
Lean mass, kg									
T1	155	54.3 (53.1, 56.0)	80	54.6 (52.2, 57.1)	44	57.2 (54.6, 59.8)	32	52.2 (49.0, 55.4)	0.035[7]
T2	156	54.7 (53.3, 56.2)	75	56.1 (53.7, 58.6)	58	55.4 (53.1, 57.7)	23	51.6 (48.1, 55.0)	<0.001[7]
T3	156	55.3 (53.7, 56.9)	41	54.7 (51.3, 58.1)	49	57.8 (55.4, 60.2)	66	53.0 (50.2, 55.9)	0.009[7,8]
P-trend		0.41		0.98		0.71		0.57	
SAT, cm^2									
T1	155	296 (287, 304)	80	272 (260, 284)	44	314 (296, 333)	32	308 (288, 329)	0.98
T2	156	295 (287, 303)	75	271 (259, 282)	58	318 (302, 334)	23	311 (289, 333)	0.19
T3	156	288 (280, 297)	41	255 (239, 272)	49	326 (309, 343)	66	299 (281, 317)	0.47
P-trend		0.17		0.037[5]		0.29		0.33	
VAT, cm^2									
T1	156	101 (95, 108)	80	68 (61.4, 74.6)	44	119 (104, 134)	32	138 (120, 155)	<0.001[7,8]
T2	156	96 (90, 102)	75	63 (56.0, 69.2)	58	117 (104, 131)	23	117 (98, 136)	<0.001[7]
T3	156	87 (80, 94)	41	60 (51.3, 69.5)	49	104 (89, 118)	66	115 (99, 131)	<0.001[7,8]
P-trend		0.001[4,5]		0.09		0.10		0.006[5]	
VAT, cm^3									
T1	156	529 (495, 563)	80	354 (320, 389)	44	620 (541, 700)	32	718 (627, 810)	<0.001[7,8]
T2	156	500 (467, 533)	75	326 (292, 361)	58	611 (541, 681)	23	609 (511, 707)	<0.001[7]
T3	156	455 (419, 492)	41	315 (267, 362)	49	541 (467, 614)	66	600 (518, 681)	<0.001[7,8]
P-trend		0.001[4,5]		0.09		0.10		0.006[5]	
VAT, g									
T1	156	489 (458, 521)	80	328 (296, 360)	44	574 (500, 647)	32	665 (580, 749)	<0.001[7,8]
T2	156	462 (432, 493)	75	302 (270, 333)	58	565 (500, 630)	23	563 (472, 654)	<0.001[7]
T3	156	421 (387, 455)	41	291 (247, 335)	49	500 (432, 568)	66	555 (479, 630)	<0.001[7,8]
P-trend		0.001[4,5]		0.09		0.10		0.006[5]	
VAT/SAT									
T1	156	0.4 (0.3, 0.4)	80	0.3 (0.2, 0.3)	44	0.4 (0.4, 0.5)	32	0.4 (0.4, 0.5)	<0.001[7]
T2	156	0.4 (0.3, 0.4)	75	0.3 (0.2, 0.3)	58	0.4 (0.4, 0.5)	23	0.4 (0.3, 0.5)	0.001[7]
T3	156	0.3 (0.3, 0.4)	41	0.3 (0.3, 0.4)	49	0.3 (0.3, 0.4)	66	0.4 (0.4, 0.5)	<0.001[7,8]
P-trend		0.24		0.23		0.008[4,5]		0.57	

(*Continued*)

TABLE 2 (*Continued*)

HEI-2010 tertiles	*n*	All, mean (*n* = 468)	*n*	18–40 y (*n* = 196)	*n*	40–60 y (*n* = 151)	*n*	60–80 y (*n* = 121)	*P*-trend[2]
Trunk fat, kg									
T1	156	10.8 (10.5, 11.1)	80	9.4 (9.0, 9.7)	44	12.0 (11.5, 12.7)	32	11.8 (11.1, 12.4)	0.009[7]
T2	156	10.5 (10.3, 10.8)	75	9.1 (8.8, 9.5)	58	11.7 (11.2, 12.2)	23	11.4 (10.7, 12.1)	0.002[7]
T3	156	10.3 (10.0, 10.6)	41	8.9 (8.5, 9.4)	49	11.7 (11.1, 12.2)	66	11.2 (10.7, 11.8)	<0.001[7]
P-trend		0.004[5]		0.05[5]		0.26		0.10	

[1]Values are means (95% CIs) unless otherwise indicated. GLM used to obtain adjusted means including adjustment for sex, race/ethnicity, PAL, age, alcohol, total energy intake, and total body fat. GLM for BMI, percentage body fat, and total body fat did not include adjustment for total body fat. GLM, general linear model; HC, hip circumference; PAL, physical activity level; SAT, subcutaneous adipose tissue; VAT, visceral adipose tissue; WC, waist circumference; WHR, waist-hip ratio.
[2]GLM used to obtain trend by HEI-2010 tertiles between age groups including adjustment for sex, race/ethnicity, PAL, alcohol, total energy intake, and total body fat. Trend test for BMI, percentage body fat, and total body fat did not include adjustment for total body fat.
[3]GLM used to obtain trend by age groups between tertiles; including adjustment for sex, race/ethnicity, PAL, age, alcohol, total energy intake, and total body fat. Trend test for BMI, percentage body fat, and total body fat did not include adjustment for total body fat.
[4]Significant difference by GLM between HEI-2010 tertile 3 and HEI-2010 tertile 2.
[5]Significant difference by GLM between HEI-2010 tertile 3 and HEI-2010 tertile 1.
[6]Missing values: 8 for waist circumference, hip circumference, and waist hip ratio.
[7]Significant difference by GLM between 60–80 and 18–40.
[8]Significant difference by GLM between 60–80 and 40–60.

a significant inverse relationship between diet quality, body fat percentage, and total body fat was observed in whites and Asians. Among white and black or African American participants, diet quality was inversely associated with insulin (**Supplemental Table 5**). Specifically for Asian participants, insulin was significantly lower in T3 vs. T2.

Men and women with the highest diet quality had significantly lower BMI, body fat percentage, total body fat, insulin, and HOMA-IR compared to those with the lowest diet quality (Supplemental **Tables 7, 8**).

Discussion

In this cross-sectional analysis of multiethnic adults, for the whole study sample and specifically among participants aged 60–80 y, diet quality was inversely related to VAT, with participants with the highest diet quality having lower VAT than those the lowest diet quality. In the per-HEI component analyses with VAT, for each age group, no single HEI-component was significantly associated with VAT. This highlights the importance of focusing public health attention on improving overall diet quality to help minimize VAT amounts during adulthood.

Differences in VAT amounts by ethnicity (20, 21) and by age (2, 4, 14) have previously been explored. The current analyses are novel due to the multiethnic study population of young, middle, and older adults, which allowed for stratified analyses by age and testing the association between diet quality and VAT across age groups in a racially and ethnically diverse population. For white participants there was a significant inverse trend between diet quality and VAT, and Asian participants in T3 had significantly lower VAT than those in T2. The sample size of the current study was adequate to detect the observed differences in VAT between HEI tertiles as significant with 80% power and $\alpha = 0.05$. However, all models were adjusted for multiple confounders; thus, with a larger sample size, a significant inverse trend between diet quality and VAT may have been seen for the black or African American and Other race/ethnicity groups. The differences in VAT results between race/ethnicity groups is an area for future investigation. For both men and women, those with higher diet quality had significantly lower VAT. Therefore, sex did not appear to modify these effects.

Among participants aged 40–60 y, VAT/SAT was inversely related to diet quality, indicating that following a higher-quality diet may help to preferentially promote storage of SAT rather than VAT in adults aged 40–60 y. Participants aged 60–80 y had higher VAT, WC, HC, WHR, lean mass, VAT/SAT, and trunk fat than participants aged 18–40 y. Despite the effect of aging on VAT, following a higher-quality diet appears to lower amounts of VAT, percentages of body fat, and total body fat among participants aged 60–80 y.

In the older age group there were significantly higher amounts of HBA1c, HOMA-IR, and fasting glucose than in the younger age group. Among those 60–80 y, following a higher quality diet was not associated with lower amounts of these biomarkers of diabetes risk, possibly because these blood-based biomarkers were being controlled through medication (37). Among younger and middle-aged adults, those with higher diet quality had significantly lower HOMA-IR and insulin, compared to those with lower diet quality.

For older adults, the significant association found between diet quality and VAT is consistent with results from the MEC-APS (average age 69.2 y) (18). For middle-aged adults, to our knowledge, this is the first time a significant association between VAT/SAT and diet quality among a multiethnic population of men and women has been published. In this current analysis, participants aged 40–60 y in T3 (i.e., highest diet quality) had lower VAT and higher SAT than participants in T1, although these differences were not significant, probably due to the limited sample size. In comparison, in the Framingham Heart Study, among a larger sample of 2926 participants with a mean age of 50 ± 10 y, a significant inverse relationship was found between diet quality and VAT (23). Among younger adults, the nonsignificant relations between diet quality and VAT may be due to their relatively low amounts of VAT.

In the current study, an inverse relationship of diet quality with BMI, body fat percentage, and total body fat was found for the whole study sample. These results are consistent with those found in the MEC-APS,

TABLE 3 Adjusted means (95% CI) for blood-based biomarkers of type 2 diabetes and CVD risk by Healthy Eating Index-2010 tertiles and age groups

HEI-2010 Tertiles[1,2]	*n*	All	*n*	18–40 y	*n*	40–60 y	*n*	60–80 y	*P*-trend[3]
HbA1c, %									
T1	155	5.4 (5.3, 5.5)	53	5.1 (5.0, 5.3)	56	5.6 (5.3, 5.9)	30	5.6 (5.4, 5.9)	<0.001[4]
T2	153	5.5 (5.3, 5.6)	56	5.2 (5.1, 5.3)	34	5.5 (5.3, 5.8)	42	5.7 (5.4, 6.0)	0.008[4]
T3	155	5.3 (5.2, 5.4)	71	5.1 (5.0, 5.3)	36	5.3 (5.0, 5.6)	36	5.6 (5.3, 5.9)	<0.001[4,5]
P-trend[6]		0.11[7]		0.85		0.06		0.72	
Insulin, uU/mL									
T1	151	13.0 (11.6, 14.5)	52	11.3 (9.4, 13.1)	54	14.7 (12.0, 17.5)	30	14.7 (10.2, 19.1)	0.18
T2	154	10.4 (9.0, 11.8)	57	9.1 (7.3, 10.9)	34	9.9 (7.5, 12.3)	42	14.1 (9.3, 18.9)	0.07
T3	155	9.2 (7.6, 10.7)	71	7.8 (5.3, 10.3)	36	8.5 (6.0, 11.1)	36	12.4 (8.5, 16.3)	0.004[4,5]
P-trend		<0.001[8]		0.005[8]		<0.001[8]		0.28	
HOMA-IR									
T1	151	3.1 (2.7, 3.5)	52	2.4 (2.0, 2.9)	54	3.6 (2.8, 4.3)	30	3.7 (2.3, 5.2)	0.021[4]
T2	153	2.6 (2.2, 3.0)	56	2.0 (1.6, 2.4)	34	2.5 (1.8, 3.1)	42	3.7 (2.2, 5.3)	0.022[4]
T3	155	2.1 (1.6, 2.5)	71	1.6 (1.0, 2.2)	36	1.9 (1.2, 2.5)	36	3.1 (1.8, 4.4)	0.001[4,5]
P-trend		<0.001[8]		0.005[8]		0.001[8]		0.33	
Glucose, mg/dL									
T1	155	93.2 (89.7, 96.7)	53	86.4 (83.0, 89.7)	56	96.2 (88.4, 104.1)	30	97.4 (85.6, 109.3)	0.034[4]
T2	154	95.8 (92.3, 99.2)	57	86.4 (83.0, 89.8)	34	99.3 (92.4, 106.2)	42	103.8 (91.0, 116.5)	0.008[4]
T3	155	90.5 (86.8, 94.3)	71	82.2 (77.5, 86.9)	36	90.9 (83.7, 98.2)	36	99.5 (88.9, 110.0)	<0.001[4,5]
P-trend		0.23[7]		0.08		0.27[7]		0.72	
ALT, μmol/L									
T1	155	25.9 (23.5, 28.3)	53	24.8 (20.3, 29.4)	56	25.4 (21.8, 29.0)	30	25.9 (21.0, 30.9)	0.77
T2	154	23.3 (21.0, 25.7)	57	20.2 (15.6, 24.7)	34	26.2 (23.0, 29.4)	42	22.9 (17.5, 28.1)	0.82
T3	155	24.1 (21.5, 26.7)	71	21.2 (14.9, 27.5)	36	26.6 (23.3, 30.0)	36	23.9 (19.5, 28.3)	0.75
P-trend		0.24		0.24		0.58		0.38	
Cholesterol, mg/dL									
T1	155	188.9 (180.8, 197.1)	53	178.2 (167.4, 189.1)	56	196.2 (180.8, 211.5)	30	183.5 (158.6, 208.5)	0.40
T2	154	193.4 (185.3, 201.4)	57	180.8 (169.9, 191.6)	34	203.3 (189.8, 216.8)	42	192.1 (165.3, 218.8)	0.36
T3	155	190.1 (181.3, 199.0)	71	174.1 (159.0, 189.2	36	200.0 (185.8, 214.2)	36	198.9 (176.7, 221.0)	0.017[4]
P-trend		0.82		0.58		0.68		0.20	
HDL, mg/dL									
T1	155	59.2 (56.5, 61.9)	53	54.1 (50.0, 60.0)	56	62.5 (57.2, 67.9)	30	62.0 (54.8, 69.1)	0.010[4]
T2	154	61.9 (59.2, 64.5)	57	60.6 (56.7, 64.6)	34	62.1 (57.5, 66.8)	42	63.7 (56.0, 71.3)	0.62
T3	155	59.9 (57.0, 62.8)	71	55.9 (50.4, 61.4)	36	64.5 (59.6, 69.4)	36	60.9 (54.5, 67.2)	0.30[5]
P-trend		0.66		0.49		0.54		0.74	
LDL, mg/dL									
T1	152	110.5 (104.4- 117.0)	52	109.5 (100.9, 118.2)	55	111.0 (99.0, 123.1)	30	105.2 (85.1, 125.4)	0.98
T2	152	111.6 (105.3, 118.0)	57	106.0 (97.4, 114.6)	33	118.4 (107.7, 129.1)	42	106.0 (84.4, 127.6)	0.73[5]
T3	155	111.5 (104.6, 118.5)	71	106.6 (94.7, 118.5)	36	113.2 (102.1, 124.4)	36	118.0 (100.1, 135.9)	0.08
P-trend		0.81		0.61		0.76		0.18	
TG, mg/dL									
T1	155	108.0 (95.7, 120.2)	53	103.9 (86.4, 121.3)	56	110.8 (82.7, 138.9)	30	104.1 (75.3, 132.9)	0.98
T2	153	99.3 (87.2, 111.3)	57	88.6 (71.2, 106.1)	33	102.8 (78.0, 127.5)	42	106.2 (75.4, 137.1)	0.16
T3	155	95.7 (82.5, 108.9)	71	80.0 (55.9, 104.2)	36	103.7 (77.7, 129.8)	36	97.7(72.2, 123.2)	0.021[4]
P-trend		0.11		0.045[8]		0.68		0.64	

[1]Values are means (95% CIs) unless otherwise indicated. GLM used to obtain adjusted means including adjustment for sex, race/ethnicity physical activity level (PAL), age, alcohol, total energy intake, and total body fat. ALT, alanine transaminase;TG: triglycerides.
[2]Missing values: 4 for ALT, cholesterol, HDL, and glucose; 5 for TG and HbA1c; 9 for LDL, and 7 for insulin and HOMA-IR.
[3]GLM used to obtain trend by HEI-2010 tertiles between age groups; including adjustment for sex, race/ethnicity, PAL, alcohol, total energy intake, and total body fat.
[4]Significant difference by GLM between 60–80 and 18–40.
[5]Significant difference by GLM between 60–80 and 40–60.
[6]GLM used to obtain trend by age groups between tertiles; including adjustment for sex, race/ethnicity, PAL, age, alcohol, total energy intake, and total body fat.
[7]Significant difference by GLM between HEI-2010 tertile 3 and HEI-2010 tertile 2.
[8]Significant difference by GLM between HEI-2010 tertile 3 and HEI-2010 tertile 1.

with diet quality being inversely associated with BMI and total body fat (18).

Diet quality among participants in this study appears to be higher than that in the wider US population. Mean HEI-2010 scores for participants aged 18–40, 40–60, and 60–80 y were 64.9, 66.9, and 71.1, respectively. According to the 2015 Dietary Guidelines Advisory Committee (DGAC) Report, the average HEI-2010 scores for people aged 19–30, 31–50, 51–70, and ≥ 71 y in the United States were 50.5, 57.4, 61.6, and 65.8, respectively (38). Characteristics of participants in the current study compared with characteristics of participants in NHANES

2009–2010 in the 2015 DGAC report (38) may explain the differences seen in HEI-2010 scores between these 2 populations. For example, women generally have higher diet quality scores than men (23, 39), and in this current study ∼56% of participants were women, compared to ∼50% in NHANES 2009–2010 (38).

The relatively high diet quality scores of Shape Up! Adult participants may also explain the relatively low amounts of VAT across each age group, and the nonsignificant differences in most blood-based biomarkers of diabetes and CVD risk across HEI-2010 tertiles. Despite the relatively low amounts of VAT; we did consistently see significantly lower VAT, HOMA-IR, and insulin in those with the highest diet quality compared with those with the lowest diet quality.

Similar to this current study, MEC-APS participants were recruited from Hawaii and Los Angeles through stratified sampling and included white, black or African American, Native Hawaiian, Japanese American, and Hispanic or Latino participants. The age range of MEC-APS participants was 60–77 y and the mean HEI-2010 score was 72.7 (18). These results closely match the mean HEI-2010 score of 71.1 among participants in the 60–80 y group in the current study. MEC-APS participants completed an FFQ validated for use among multiethnic populations that include Japanese Americans (40); whereas, the DHQ II FFQ has been validated in white, black or African American, and Hispanic or Latino populations and has yet to be validated for Asian Americans (41–43). The positive linear association between HEI-2010 scores and age in the current study is consistently seen in the literature among multiethnic groups (18, 39). This evidence suggests that the DHQ II may be a reliable method for collection of dietary data among multiethnic populations that include Asian Americans. Further research is needed to confirm these findings.

A strength of this study was the inclusion of DXA-based VAT measures. Computed tomography (CT) and MRI are considered the gold standards for measurement of VAT (42–46). However, DXA-based VAT strongly correlates with CT, and DXA can be performed with lower exposure of radiation to both the participant and examiner (46, 47). Additional strengths were the inclusion of a racially/ethnically diverse population of young, middle age, and older adults, with adjustment for known confounders, and the use of the criterion of a validated HEI-2010 dietary index for the assessment of diet quality (48). A limitation of this study was the sample size, which did not allow for stratification by both sex and race/ethnicity in the same model. In addition, being a cross-sectional study, a causal relationship between diet quality and VAT cannot be derived. Due to the stratified recruitment and convenience sampling, results of this study may not be representative of the US population (25). The study size also limited the number of covariates included in the models. Therefore, other factors not controlled for may have affected study results, e.g., participant smoking status, socioeconomic status, pharmacological agents, and menopausal status (4). Previous research found that the DHQ underestimates energy and protein intake (49); however, all participants were subjected to this bias. Administering the DHQ II through REDCap may have changed the user experience when completing the DHQ II; consequently, results may not align with those for previous validation of the DHQ. However, despite these limitations, associations found between diet quality and VAT were as expected.

In conclusion, a higher quality diet was associated with lower amounts of VAT, overall adiposity, insulin, and insulin resistance among a multiethnic group with an age range of 18–80 y. In particular, following a higher quality diet may help to minimize VAT accumulation in adults aged 60–80 y and preferentially promote storage of SAT rather than VAT in adults aged 40–60 y. These results also highlight the potential benefits to adults of adhering to a high-quality diet, such as the 2010 Dietary Guidelines for Americans, to help optimize health outcomes.

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