Diet Quality in Midadulthood Predicts Visceral Adiposity and Liver Fatness in Older Ages: The Multiethnic Cohort Study

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Objective: The relationship of diet quality assessed by established indices (HEI-2010, AHEI-2010, aMED, DASH) with adiposity measures was examined, especially visceral adipose tissue (VAT) and nonalcoholic fatty liver (NAFL).

Methods: Close to 2,000 participants of the Multiethnic Cohort completed validated food frequency questionnaires at cohort entry (1993-1996) and clinic visit (2013-2016) when they underwent whole-body dual-energy x-ray absorptiometry and abdominal magnetic resonance imaging scans. Linear regression was used to estimate mean values of adiposity measures by dietary index tertiles at baseline and standardized regression coefficients (βs) after adjusting for total adiposity and other covariates. Logistic regression of VAT and NAFL on dietary indices was also performed.

Results: Higher dietary quality scores at cohort entry were inversely related to all adiposity measures, with the strongest associations for percent liver fat (βs = −0.14 to −0.08), followed by VAT (βs = −0.11 to −0.05), BMI (βs = −0.11 to −0.06), and total body fat (βs = −0.09 to −0.05). Odds ratios adjusted for total adiposity ranged between 0.57 and 0.77 for NAFL and between 0.41 and 0.65 for high VAT when comparing the highest versus lowest tertiles of diet quality.

Conclusions: These longitudinal findings indicate that maintaining a high-quality diet during mid-to-late adulthood may prevent adverse metabolic consequences related to VAT and NAFL.

Introduction

Accumulation of fat as visceral adipose tissue (VAT) and the presence of nonalcoholic fatty liver (NAFL) appear to contribute significantly to the adverse metabolic consequences of excess body weight, in particular inflammation and cardiometabolic conditions (1,2). A recent review suggested that noncaloric qualitative aspects of diet, such as dietary fiber, calcium, fructose, and also dietary patterns as described by diet index scores, predominantly affect VAT, whereas subcutaneous fat (SAT) may be determined more by an excess in total energy intake (3). To capture the global effects of multiple qualitative aspects of diet, two approaches are commonly distinguished: a posteriori-derived dietary patterns are identified through exploratory data-driven techniques (4), while a priori indices are constructed on the basis of dietary recommendations and existing scientific evidence relating dietary intakes to chronic diseases. Based on the hypothesis that diet quality influences VAT and NAFL, we prospectively examined the association of four a priori-defined dietary indices, namely the Healthy Eating Index (HEI-2010), the Alternative Healthy Eating Index (AHEI-2010), the alternate Mediterranean Diet score (aMED), and the Dietary Approaches to Stop Hypertension (DASH), with dual-energy x-ray absorptiometry (DXA)- and magnetic resonance imaging (MRI)-derived adiposity measures in a large subgroup of Multiethnic Cohort (MEC) participants.

Methods

Study population

Study participants were recruited from the MEC, an ongoing prospective study in Hawaii and Los Angeles, California, of diet, lifestyle, and genetic risk factors for cancer and other chronic diseases with more than 215,000 men and women, aged 45 to 75 years at recruitment, of mainly Japanese American, Native Hawaiian, white, African American, and Latino ancestry. All cohort members completed a 26-page baseline questionnaire by mail in 1993 to 1996 (5).

Funding agencies: This work was supported by the US National Institutes of Health (P01CA169530, U01CA164973, P30CA071789, UL1TR000130).

Disclosure: The authors declared no conflicts of interest.

Received: 7 December 2016; Accepted: 3 April 2017; Published online 26 July 2017. doi:10.1002/oby.21868
The current Body Imaging Study (BIS) targeted a subset of MEC members who were 60 to 72 years of age as of January 2013 and living in the catchment area of the study clinics. Mailed invitations were followed by screening telephone calls to exclude individuals with the following characteristics: current reported BMI outside the target range (18.5-40 kg/m²), current or recent (<2 years) smoking, soft or metal implants (other than knee or hip replacement) or amputations, claustrophobia, insulin treatment, thyroid medication, or other serious health conditions. Individuals with weight change of >9 kg or undergoing treatments or procedures that were likely to affect adiposity or biomarkers of interest, e.g., antibiotics, colonoscopy, chemotherapy, radiation of abdomen/pelvis, corticosteroids, weight loss drugs, or estrogen/androgen blocker replacements, were deferred for 6 months, at which time their eligibility was reconsidered.

Recruitment for BIS was conducted during 2013 to 2016 within 60 sex/ethnicity/BMI strata (18.5-21.9; 22-24.9; 25-26.9; 27-29.9; 30-34.9; 35-40 kg/m²) to balance the composition of the study population. The participation rate was 15.6% out of the 13,884 contacted, excluding the 4,455 persons who were willing but ineligible. Eligible cohort members visited study clinics to complete anthropometric and imaging measurements, fasting blood sample collection, and questionnaires. In Hawaii, participants completed the protocol at the University of Hawaii (UH) Cancer Center, except for the MRI scan, which was performed at the UH/Queen’s Medical Center MR Research Center, mostly within 2 weeks of the clinic visit. In Los Angeles, participants completed the study protocol in one visit to the Southern California Clinical and Translational Science Institute (SC CTSI) at the Keck School of Medicine of University of Southern California (USC). Institutional Review Boards at UH (CHS#17200) and USC (#HS-12-00623) approved the protocol, and all participants signed informed consent forms.

Anthropometry and imaging
During the BIS clinic visit, trained technicians measured height (Heightronic model #235A at UH; Seca #240 at USC) and weight (Scale-Tronix model #5102 at UH; Health o meter Professional ProPlus at USC). The DXA and MRI imaging protocols have been described in detail previously (6,7). Total and regional body composition was determined by a whole-body DXA scan (Hologic Discovery A at UH and USC), which was calibrated using daily quality control phantoms. DXA image files from both study sites were centrally analyzed at the University of California, San Francisco. Fat mass, overall and in the trunk, arms, and legs, was estimated in kilograms. BMI and muscle mass index were computed by dividing total weight or total DXA muscle mass, respectively, by the square of height in meters. Abdominal MRI scans were acquired on 3-Tesla scanners (Siemens TIM Trio, Erlangen, Germany, software version VB13 at UH; General Electric HDx, Milwaukee, Wisconsin, software release 15M4 at USC) to assess VAT and SAT areas at four cross-sectional lumbar positions (L1-L2, L2-L3, L3-L4, L4-L5) using an axial gradient-echo sequence with water-suppression and breath-hold (25 slices, 10 mm thickness, 2.5 mm gap, TR/TE = 140/2.6 ms, 70° flip angle). Percent liver fat was estimated from a series of axial triple gradient-echo Dixon-type scans (10 mm slices, no gap, TE = 2.4, 3.7, and 5.0 ms, TR = 160 ms, 25° flip angle) by measuring and analyzing in-phase, out-of-phase, and in-phase signals in a manually placed circle in the liver selected for not including hepatic veins or biliary ducts (6). MRI measures were calibration adjusted for minimal differences between the scanners at the two study sites based on 15 healthy volunteers (BMI 21.8-39.6 kg/m²) who were scanned at both sites within a week and regressions of the Hawaii on the Los Angeles estimates.

Dietary and lifestyle assessment
The mailed self-administered survey at cohort entry and the BIS visit included a quantitative food frequency questionnaire (QFFQ) with more than 180 food items, as well as questions on demographics, medical conditions, anthropometric measures, physical activity, and other lifestyle factors (5,8). The validated and calibrated QFFQ has several unique attributes (8), including ethnic-specific foods, reliance on a food composition table specific to the MEC, and use of a large recipe database (9). Questionnaire information about average time spent in sleep and in sedentary, moderate, and vigorous activities on a typical day was used to compute daily metabolic equivalents of tasks (METs).

Diet quality indices
The relative importance of food groups differed across the four a priori indices (Table 1), which had previously been examined in

| TABLE 1 Components of the HEI-2010, AHEI-2010, aMED, and DASH scores |
|---------------------------------------------------------------|
| **HEI-2010** | **AHEI-2010** | **aMED** | **DASH** |
|----------------------------------|----------------|--------|--------|
| Maximum score | 100 | 110 | 9 | 40 |
| Total vegetables | [↑] | [↑] | [↑] | [↑] |
| Vegetables excluding potatoes | [↑] | [↑] | [↑] | [↑] |
| Total fruits | [↑] | [↑] | [↑] | [↑] |
| Whole fruits | [↑] | [↑] | [↑] | [↑] |
| Nuts, seeds, and legumes | [↑] | [↑] | [↑] | [↑] |
| Nuts and legumes | [↑] | [↑] | [↑] | [↑] |
| Nuts | [↑] | [↑] | [↑] | [↑] |
| Legumes | [↑] | [↑] | [↑] | [↑] |
| Fish | [↑] | [↑] | [↑] | [↑] |
| Seafood and plant protein | [↑] | [↑] | [↑] | [↑] |
| Total protein foods | [↑] | [↑] | [↑] | [↑] |
| Red and processed meat | [↓] | [↓] | [↓] | [↓] |
| Dairy | [↑] | [↑] | [↑] | [↑] |
| Oils/fats | [↑] | [↑] | [↑] | [↑] |
| Alcohol | [↑] | [↑] | [↑] | [↑] |
| Whole grains | [↑] | [↑] | [↑] | [↑] |
| Refined grains | [↑] | [↑] | [↑] | [↑] |
| Empty calories | [↓] | [↓] | [↓] | [↓] |
| SSB and fruit juice | [↓] | [↓] | [↓] | [↓] |
| Sodium | [↓] | [↓] | [↓] | [↓] |

↑ Components were positively scored such that a higher intake is associated with a higher score.
↓ Components were inversely scored such that a higher intake is associated with a lower score.
*Empty calories: energy from solid fat, added sugars, and alcohol.
AHEI, Alternative Healthy Eating Index; aMED, alternate Mediterranean Diet score; DASH, Dietary Approaches to Stop Hypertension; HEI, Healthy Eating Index; SSB, sugar-sweetened beverage.
TABLE 2 Characteristics of the study population by BMI status at cohort entry and clinic visit

|                          | Allb | Normal weightc | Overweight | Obesity |
|--------------------------|------|----------------|------------|---------|
| N                        | 1,861| 542            | 750        | 569     |
| Sex                      |      |                |            |         |
| Men                      | 923  | 242            | 420        | 261     |
| Women                    | 938  | 300            | 330        | 308     |
| Ethnicity                |      |                |            |         |
| White                    | 411  | 147            | 164        | 100     |
| African American         | 317  | 70             | 117        | 130     |
| Native Hawaiian          | 307  | 74             | 115        | 118     |
| Japanese American        | 434  | 178            | 183        | 73      |
| Latino                   | 392  | 73             | 171        | 148     |
| Age, y                   |      |                |            |         |
| Cohort entry             | 48.3 | 48.4 ± 2.5     | 48.3 ± 2.6 | 48.2 ± 2.5 |
| Clinic visit             | 69.2 | 62.7 ± 2.7     | 69.2 ± 2.7 | 69.4 ± 2.7 |
| Physical activity, METs  |      |                |            |         |
| Cohort entry             | 2.5  | 4.0 ± 1.8      | 1.8 ± 4.0  | 1.8 ± 4.0 |
| Clinic visit             | 2.7  | 4.1 ± 3.9      | 2.6 ± 4.1  | 1.8 ± 4.6 |
| Alcohol intake, drinks/day|      |                |            |         |
| Cohort entry             | 0.7  | 0.6 ± 1.1      | 0.7 ± 1.5  | 0.7 ± 1.6 |
| Clinic visit             | 0.7  | 0.8 ± 1.6      | 0.7 ± 1.4  | 0.6 ± 1.6 |
| Total energy, kcal       |      |                |            |         |
| Cohort entry             | 2,224 | 2,094 ± 941   | 2,161 ± 966 | 2,360 ± 1,161 |
| Clinic visit             | 1,883 | 1,784 ± 757   | 1,844 ± 825 | 2,027 ± 1,207 |
| HEI-2010                 |      |                |            |         |
| Cohort entry             | 70.1 | 71.0 ± 9.5     | 69.9 ± 9.5 | 69.5 ± 9.5 |
| Clinic visit             | 72.7 | 74.6 ± 9.9     | 72.6 ± 9.3 | 70.8 ± 9.5 |
| Change                   | 2.6  | 3.7 ± 9.2      | 2.7 ± 9.7  | 1.4 ± 8.6 |
| AHEI-2010                |      |                |            |         |
| Cohort entry             | 63.8 | 64.9 ± 9.7     | 63.6 ± 9.8 | 63.0 ± 8.8 |
| aMED                     | 4.1  | 4.1 ± 1.8      | 4.0 ± 1.8  | 4.1 ± 1.8 |
| DASH                     |      |                |            |         |
| Cohort entry             | 23.3 | 23.7 ± 4.6     | 23.2 ± 4.3 | 23.1 ± 4.1 |
| Muscle mass index, kg/m² |      | 7.5 ± 1.4      | 6.4 ± 1.0  | 7.5 ± 1.1  | 8.4 ± 1.3 |
| Total body fat, kg       |      | 25.5 ± 8.7     | 17.8 ± 4.4 | 24.2 ± 4.8 | 34.5 ± 7.7 |
| Trunk fat, kg            | 13.5 | 9.0 ± 2.6      | 13.1 ± 2.5 | 18.5 ± 3.9 |
| Trunk/leg fat ratio      | 1.6  | 1.4 ± 0.4      | 1.7 ± 0.4  | 1.7 ± 0.5 |
| VAT area (L1-L5 mean), cm²| 168  | 100 ± 49       | 173 ± 63   | 227 ± 87 |
| VAT/SAT ratio            | 0.8  | 0.7 ± 0.4      | 0.9 ± 0.5  | 0.8 ± 0.5 |
| Percent liver fat, %     | 5.7  | 3.7 ± 3.2      | 5.8 ± 4.5  | 7.5 ± 5.0 |
| Nonalcoholic fatty liver (>5.5%), % | 33.4 | 12.1            | 34.4        | 52.9     |
| High VAT (>150 cm²), %   | 52.9 | 15.4           | 59.9       | 80.7     |

*Means ± standard deviations shown except for sex and ethnicity where participant numbers are given.
*Missing values: 57 for diet at cohort entry, 36 for diet at clinic visit, 21 for DXA, 60 for MRI.
*BMI at baseline categorized as normal weight (18.5-24.9 kg/m²), overweight (25.0-29.9 kg/m²), or obesity (≥30 kg/m²).

Abbreviations: AHEI, Alternative Healthy Eating Index; aMED, alternate Mediterranean Diet score; DASH, Dietary Approaches to Stop Hypertension; HEI, Healthy Eating Index; MET, metabolic equivalents of tasks; SAT, subcutaneous adipose tissue; VAT, visceral adipose tissue.

MEC in relation to mortality (10) and diabetes (11). The HEI-2010 reflects the 2010 Dietary Guidelines for Americans with higher scores indicating better adherence to federal dietary guidelines (12). The AHEI-2010 (13) and the aMED (14) include foods and nutrients shown to be predictive of chronic disease risk. The DASH includes eight components that are emphasized in the DASH diet developed for hypertension management (15). The four indices were calculated for the QFFQ at cohort entry and the HEI-2010 also for the QFFQ at the BIS clinic visit.

Statistical analysis
The analysis examined BMI, four DXA-derived measures (muscle mass index, DXA total and trunk fat, trunk/leg fat ratio), and five MRI-based measures (mean VAT for L1-L5, VAT/SAT ratio, percent liver fat, NAFL defined as >5.5%, high VAT defined as ≥150 cm²) in relation to the four dietary indices at cohort entry. The indices were divided into three categories, denoted as tertiles, although the categories do not always represent thirds (14,15). To assess change in diet quality since cohort entry as assessed by HEI-2010, the scores at cohort entry and at the clinic visit were dichotomized into low and high using their respective medians and combined into a four-level variable describing status at both times (low/low, low/high, high/low, high/high). A similar analysis was not performed for the other indices because some the component scores are based on the dietary intake distribution of the population under study and, thus, are not comparable over time.
TABLE 3 Current mean (95% CL) adiposity measures (2013–2016) by tertiles of dietary indices at cohort entry (1993–1996)\(^a\)

|                        | HEI-2010\(^b\) | AHEI-2010 | aMED | DASH\(^c\) |
|------------------------|---------------|-----------|------|------------|
| **BMI, kg/m\(^2\)**    |               |           |      |            |
| T1 601                 | 28.1          | 27.7, 28.5| 28.4 | 28.0, 28.8 |
| T2 602                 | 28.0          | 27.6, 28.5| 28.0 | 27.5, 28.6 |
| T3 601                 | 27.6          | 27.2, 27.9| 27.4 | 27.1, 27.8 |
| \(\beta_1\) (95%CI)\(^d\) | -0.06 (-0.11 to -0.01) | -0.09 (-0.13 to -0.04) | -0.08 (-0.13 to -0.03) | -0.11 (-0.16 to -0.06) |
| **Muscle mass index, kg/m\(^2\)** |               |           |      |            |
| T1 591                 | 7.47          | 7.39, 7.55| 7.53 | 7.45, 7.61 |
| T2 601                 | 7.51          | 7.43, 7.59| 7.50 | 7.42, 7.58 |
| T3 599                 | 7.44          | 7.36, 7.52| 7.40 | 7.32, 7.48 |
| \(\beta_2\) (95%CI)\(^d\) | -0.02 (-0.06 to 0.01) | -0.04 (-0.07 to 0.01) | -0.04 (-0.08 to 0.001) | -0.03 (-0.07 to 0.003) |
| **Total body fat, kg** |               |           |      |            |
| T1 592                 | 25.7          | 25.1, 26.3| 26.3 | 25.7, 26.9 |
| T2 598                 | 25.4          | 24.8, 26.0| 25.7 | 24.9, 26.5 |
| T3 595                 | 24.8          | 24.2, 25.5| 24.6 | 24.0, 25.2 |
| \(\beta_3\) (95%CI)\(^d\) | -0.05 (-0.09 to -0.01) | -0.08 (-0.12 to -0.04) | -0.07 (-0.12 to -0.02) | -0.09 (-0.14 to -0.05) |
| **Trunk fat\(^f\), kg** |               |           |      |            |
| T1 581                 | 13.6          | 13.5, 13.8| 13.6 | 13.4, 13.7 |
| T2 580                 | 13.5          | 13.4, 13.6| 13.5 | 13.3, 13.6 |
| T3 577                 | 13.4          | 13.3, 13.5| 13.4 | 13.3, 13.5 |
| \(\beta_4\) (95%CI)\(^d\) | -0.02 (-0.04 to 0.00) | -0.02 (-0.03 to 0.01) | -0.02 (-0.04 to 0.01) | -0.04 (-0.06 to 0.03) |
| **Trunk/leg fat ratio\(^g\)** |               |           |      |            |
| T1 546                 | 1.62          | 1.58, 1.65| 1.60 | 1.57, 1.63 |
| T2 547                 | 1.57          | 1.54, 1.60| 1.57 | 1.53, 1.61 |
| T3 547                 | 1.55          | 1.52, 1.58| 1.56 | 1.53, 1.59 |
| \(\beta_5\) (95%CI)\(^d\) | -0.05 (-0.10 to -0.01) | -0.05 (-0.09 to 0.01) | -0.03 (-0.08 to -0.01) | -0.12 (-0.17 to -0.07) |
| **VAT area (L1-L5 mean), m\(^2\)** |               |           |      |            |
| T1 582                 | 175           | 171, 180 | 172 | 167, 177  |
| T2 583                 | 169           | 164, 173 | 170 | 166, 178  |
| T3 554                 | 161           | 157, 166 | 163 | 159, 165  |
| \(\beta_6\) (95%CI)\(^d\) | -0.06 (-0.09 to -0.03) | -0.07 (-0.10 to -0.03) | -0.05 (-0.08 to -0.01) | -0.11 (-0.14 to -0.07) |
| **VAT/SAT ratio\(^h\)** |               |           |      |            |
| T1 582                 | 0.86          | 0.83, 0.89| 0.85 | 0.82, 0.88 |
| T2 583                 | 0.83          | 0.80, 0.86| 0.83 | 0.80, 0.86 |
| T3 584                 | 0.78          | 0.75, 0.81| 0.80 | 0.77, 0.83 |
| \(\beta_7\) (95%CI)\(^d\) | -0.05 (-0.09 to -0.01) | -0.06 (-0.10 to -0.03) | -0.04 (-0.08 to -0.01) | -0.11 (-0.15 to -0.07) |
| **Percent liver fat, %** |               |           |      |            |
| T1 578                 | 6.3           | 5.9, 6.6 | 6.1  | 5.7, 6.4  |
| T2 578                 | 5.6           | 5.2, 5.9 | 6.1  | 5.7, 6.4  |
| T3 578                 | 5.3           | 4.9, 5.6 | 5.0  | 4.6, 5.3  |
| \(\beta_8\) (95%CI)\(^d\) | -0.10 (-0.15 to -0.05) | -0.11 (-0.16 to -0.07) | -0.08 (-0.13 to -0.02) | -0.14 (-0.19 to -0.09) |

\(^a\)General linear models used to obtain adjusted means including sex, age (continuous), ethnicity, total energy intake (log-transformed) at cohort entry, and physical activity (high vs. low) at cohort entry.
\(^b\)Adjusted for total body fat at clinic visit.
\(^c\)Adjusted for total body fat at clinic visit.
\(^d\)Adjusted for alcohol intake (categories) at cohort entry.
\(^e\)Adjusted for total body fat at clinic visit.

General linear models were used to estimate covariate-adjusted mean adiposity values for tertiles of dietary indices. To assess dose-response relations, we performed trend tests using the dietary index scores as continuous variables after standardizing all dependent and independent variables to a mean of zero and a variance of one. The standardized regression coefficients (\(\beta_i\)) and 95% confidence intervals (CI) allowed comparison of the strengths of association across dietary indices and adiposity measures. To evaluate the influence of dietary patterns across models, a \(\chi^2\) test compared the standardized slope values across the eight adiposity measures for each index and four dietary indices across each adiposity measure under the assumption of normality for the slope estimates. Logistic regression was applied to estimate odds ratios (OR) and 95% CI for the presence of NAFL (>5.5%) and high VAT (>150 cm\(^2\)) and the C statistic to compare the model fit across exposures. All models included sex, age at clinic visit, ethnicity, total energy intake (log-transformed to correct for heteroscedasticity), and physical activity (high vs. low using the median of METs) at cohort entry as covariates. The models for trunk fat, trunk/leg fat ratio, VAT, VAT/SAT ratio, and percent liver fat were further adjusted for DXA-based total body fat. Given the importance of alcohol exposure in defining NAFL, we also

Abbreviations: AHEI, Alternative Healthy Eating Index; aMed, alternate Mediterranean Diet score; CI, confidence limit; CI, confidence interval; DASH, Dietary Approaches to Stop Hypertension; HEI, Healthy Eating Index; SAT, subcutaneous fat; VAT, visceral adipose tissue.

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adjusted the HEI-2010 and DASH models for alcohol intake, whereas the AHEI-2010 and aMED incorporate alcohol intake as a scoring component (Table 1). To evaluate the influence of ethnicity, the logistic regression models were repeated without adjusting for ethnicity. Of the 1,861 participants available for analysis, values were missing in 57 for diet at cohort entry and 36 at the clinic visit, 21 for DXA, and 60 for MRI measures. Therefore, the number of participants varied slightly across models.
Results

As a result of the stratified recruitment, approximately one third of the participants within sex and ethnic groups were in the normal weight, overweight, and obesity BMI categories (Table 2). The mean ages of the 1,861 participants were 48.3 ± 2.5 years (range: 45.0-57.0) at cohort entry and 69.2 ± 2.7 years (range: 59.9-77.4) at clinic visit, with a mean follow-up time of 20.9 ± 1.2 years. All body fat measures were correlated with higher BMI categories, with the most pronounced differences for trunk fat (9.0, 13.1, 18.5 kg), VAT (100, 173, 227 cm²), and percent liver fat (3.7%, 5.8%, 7.5%). The mean HEI-2010 at clinic visit was 2.6 ± 9.3 points higher than at cohort entry. BMI at clinic visit showed the following Spearman’s correlations with total body fat (r_s = 0.83), trunk fat (r_s = 0.86), VAT (r_s = 0.65), and NAFL (r_s = 0.46; all P < 0.0001).

Higher scores for all indices at cohort entry were significantly and inversely associated with lower adiposity measures as indicated by the 95% CIs of the standardized regression coefficients (Table 3).
When we compared the strength of the adjusted associations using the magnitude of $b_s$ (Table 3), the trends were similar for BMI ($b_s = 0.11$ to $0.06$) and total body fat ($b_s = -0.09$ to $-0.05$) but weaker for trunk fat ($b_s = -0.04$ to $-0.02$). The diet quality scores were not associated with muscle mass index, except for a weak inverse association for the AHEI-2010. As for MRI-based measures, all four indices were strongly inversely related to VAT, the VAT/SAT ratio, the trunk/leg fat ratio, and percent liver fat with respective $b_s$ of $0.11$ to $0.05$, $-0.11$ to $-0.04$, $-0.12$ to $-0.03$, and $-0.14$ to $-0.08$. Although these values were higher for DASH than the other three indices for all adiposity measures except the muscle mass index, the differences across the four dietary indices were not statistically significant. For example, the respective $P$ values for the $\chi^2$ tests of VAT and NAFL across the four indices were 0.13 and 0.30. On the other hand, a $\chi^2$ test across the eight adiposity measures for DASH resulted in a $P$ value of $<0.0001$, indicating that diet quality predicted some measures better than others.

Exchanging the adherence to HEI-2010 over time (Figure 2), the current adjusted mean BMI and total body fat were lower among participants who maintained (high/high) or improved (low/high) their dietary quality, compared to those with low diet quality at clinic visit (low/low, high/low). However, for total fat-adjusted regional adiposity measures, participants who maintained a high diet quality at both times (high/high) showed the most favorable values. The difference was most pronounced again for percent liver fat with adjusted means of 6.2% (95% CI, 5.8%-6.5%) in the low/low and 4.8% (95% CI, 4.5%-5.2%) in the high/high group; the latter value was also significantly different from the low/high group (5.9%; 95% CI, 5.4%-6.4%). The respective mean VAT values were 155 cm² (95% CI, 160-165 cm²) and 176 cm² (95% CI, 171-181 cm²) for low/high and high/high groups.

We examined the association of baseline dietary indices and HEI-2010 changes over time (Figure 3) with common clinical definitions for high visceral (>150 cm²) and hepatic adiposity (>5%).
Participants in the lowest versus the highest tertile of all four indices were significantly less likely to have NAFL or high VAT (Figure 3A–3B). The ORs for participants with the highest versus lowest diet quality ranged between 0.57 and 0.77 for NAFL and between 0.41 and 0.65 for high VAT. The strongest associations were seen for DASH and HEI, in which both the ORs of the intermediate tertiles were also significantly lower than the reference tertile. When considering change in HEI-2010 from cohort entry to clinic visit (Figure 3C–3D), the risk estimates were significantly lower for only those who scored high at both times (OR = 0.55; 95% CI, 0.41–0.74 for NAFL and OR = 0.52; 95% CI, 0.38–0.71 for high VAT).

Removing ethnicity from the NAFL models lowered the C statistic for all four indices: from 0.762 to 0.684 (HEI-2010), 0.758 to 0.682 (AHEI-2010), 0.753 to 0.670 (aMED), and 0.763 to 0.693 (DASH). However, in models with white participants only, the respective values for the C statistic increased to 0.809, 0.802, 0.802, and 0.808.

Discussion

In this study with DXA- and MRI-based measures, better diet quality, as assessed by four commonly used indices based on dietary recommendations made to the general public, predicted lower adiposity. The strongest relations were seen for NAFL followed by VAT, the VAT/SAT ratio, the trunk/leg fat ratio, and BMI. Even after adjustment for total body fat, individuals in the upper tertile of diet quality had only half the risk of high VAT and NAFL compared with participants in the lower tertile of diet quality (Figure 3). Despite modest differences across indices, performance of the four dietary quality measures did not differ significantly. An analysis of HEI-2010 scores at the beginning and at the end of the 20-year study period indicates that the long-term quality of the diet is important for VAT and NAFL, although the low/high group also experienced some benefit indicating that a change in diet can be beneficial.

These findings are remarkable and novel for several reasons. The standardized comparison of DXA- and MRI-based adiposity measures suggested a strong association of diet quality with NAFL and VAT after adjustment for total body fatness. As previous reports on diet quality and obesity were mostly cross-sectional (16–18), the current results from a prospective cohort indicate the importance of consuming a high-quality diet over many years to maintain low VAT and NAFL independent of total adiposity, whereas the influence on other adiposity measures is less clear. Without MRI measures, VAT is difficult to assess, although waist and hip measurements provide some indication of abdominal adiposity (19), and investigations are under way to estimate VAT from circulating biomarkers (7).

The Mediterranean diet is the most commonly investigated a priori pattern. As in our study, it has been inversely associated with different measures of adiposity, e.g., excess body weight in several interventions (20) and waist circumference (21,22) and VAT (16) in cross-sectional reports. Similarly, NAFL as assessed by MRI was lower for consumers of a Mediterranean diet in an observational study among Greeks (23) and in a dietary trial (24). Results related to other a priori scores also agree with our findings. For example, adherence to the 2005 US Dietary Guidelines among Framingham Study participants was negatively associated with VAT measured by computed tomography in a cross-sectional design (17), lower scores of the Dietary Quality Index predicted higher MRI-derived NAFL in a Chinese population (18), and a modified diet pattern score was related to lower VAT and hepatic steatosis in the Multi-Ethnic Study of Atherosclerosis (25).

Reports based on a posteriori patterns also support an association of higher diet quality with lower VAT and NAFL. For example, dietary patterns from principal components analysis predicted VAT regain in Japanese women (26) and variation in VAT in a German population (27). High “southern” and “fast food” pattern scores were associated with higher VAT in African Americans (28), and Western dietary patterns were associated with NAFL using ultrasound (29-32) or MRI (33). In cross-sectional studies of specific foods/nutrients, high energy intake (34), sugar-sweetened beverages (17,35,36), refined grains (37), potatoes (27), fat (17), meat (17,27), and alcohol (34) have been related to low diet quality and high VAT, while dietary fiber (27), vegetables, and nuts (17) have shown inverse associations.

Strengths of the current analysis include the prospective study design with 20 years of follow-up, the repeated dietary assessment, the ethnic diversity of the study population, and the state-of-the-art assessment of adiposity using DXA and MRI, which, along with computed tomography, is a gold standard to assess VAT and NAFL (38). Limitations include the multiple testing and the possibility of false-positive results, the small number of participants by sex and ethnicity that did not allow for stratification, and the limited age range of the study sample. The restriction of our findings to white participants and previous analyses within the MEC (10,11) indicate that dietary indices may not capture diet quality as well in Native Hawaiians, Japanese Americans, and Latinos because the indices were developed in primarily white and African American populations, but further ethnic-specific analyses are warranted.

Conclusion

This analysis within a multiethnic population demonstrates for the first time with a longitudinal study design that diet quality as assessed by four established indices has a strong inverse association with measures of abdominal and liver fatness after taking into account total body fatness. This finding has important implications for the management of excess body weight, suggesting that body fat distribution beyond BMI is a critical feature to consider when advising individuals with overweight about the health effects of their regular diets, as the metabolic consequences of visceral adiposity may lead to chronic conditions, such as type 2 diabetes (39,40). Nutritional counseling that incorporates diet quality based on one of the scientifically based guidelines in addition to total energy intake may prevent the adverse health effects related to NAFL and VAT.

Acknowledgments

We thank the Multiethnic Cohort Study participants who generously donated their time and effort. We acknowledge the excellent performance of the study staff: the Recruitment and Data Collection Core staff at USC (Adelaida Irimian, Chanthel Figueroa, Brenda...
Figueroa, Carla Flores, Karla Soriano) and UH (Terrilea Burnett, Jane Yakuma, Naomi Hee, Clara Richards, Cheryl Toyofuku, Hui Chang, Janice Nako-Piburh, Reid Sakamoto, Sara Sameshima, Pacer Lee, Emamylan Pilande, Neelima Nuti, Shirley So, Maya Yamane, Juunita Kauakai), the Data Management and Analysis Core staff at USC (Zhihan Huang) and UH (Maj Earle, Joel Julian, Anne Tome, Yun Oh Jung, Emil Svrcina), and the Project Administrative Core staff at UH (Eugene Okiyama). We also thank the Body Imaging Core staff for DXA data processing at the University of California, San Francisco (Bo Fan). Finally, we are grateful to Sidney Vermeulen for her excellent work in preparing tables and figures.

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