



# Greater Scores for Dietary Fat and Grain Quality Components Underlie Higher Total Healthy Eating Index–2015 Scores, While Whole Fruits, Seafood, and Plant Proteins Are Most Favorably Associated with Cardiometabolic Health in US Adults

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## ABSTRACT

**Background:** High-quality diets reduce the risk of cardiometabolic and other chronic diseases. The dietary components that distinguish higher from lower quality diets, and their associations with health, have not been fully investigated.

**Objectives:** This study aimed to assess the component scores that underlie differences in total Healthy Eating Index (HEI)–2015 scores, quantify fatty acid (saturated, monounsaturated, polyunsaturated) intakes that comprise Fatty Acids component scores, and assess associations between component scores and cardiometabolic risk factors.

**Methods:** A cross-sectional analysis of data from the NHANES (2001–2016) was conducted. Total and component HEI-2015 scores were assessed in adult ( $\geq 19$  y) participants who provided one 24-h dietary recall ( $n = 39,799$ ). Survey-weighted mean component scores by quartile of total HEI-2015 score were determined. Regression analyses were conducted to assess fatty acid intakes across quartiles of Fatty Acids component scores. Separate regression analyses were conducted to assess associations between component scores and cardiometabolic risk factors, after adjusting for demographic characteristics and health behaviors.

**Results:** Scores for components related to dietary fat (Fatty Acids, Saturated Fats) and grain quality (Whole Grains, Refined Grains) accounted for the greatest differences in HEI-2015 scores. Higher Fatty Acids scores were primarily composed of lower saturated and greater polyunsaturated fat intakes. Whole Fruits, and Seafood and Plant Proteins, were most favorably associated with cardiometabolic risk factors including anthropometric measures ( $P < 0.001$ ), systolic blood pressure ( $P < 0.01$ ), glycemic markers (Whole Fruits only,  $P < 0.01$ ), and HDL cholesterol and triglycerides (Seafood and Plant Proteins only,  $P < 0.001$ ).

**Conclusions:** Average diet quality in US adults is suboptimal. Higher quality diets are primarily distinguished by the types of fats and grain-based foods that are consumed. Interventions targeting dietary components that are most favorably associated with cardiometabolic risk factors—whole fruits, seafood, and plant proteins—may have the greatest impact on disease risk. *Curr Dev Nutr* 2021;5:nzab015.

**Keywords:** HEI-2015, diet quality, NHANES, cardiometabolic, cholesterol, dietary pattern

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Supplemental Tables 1–3 are available from the “Supplementary data” link in the online posting of the article and from the same link in the online table of contents at <https://academic.oup.com/cdn/>.

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Abbreviations used: CVD, cardiovascular disease; DGA, Dietary Guidelines for Americans; HEI, Healthy Eating Index; PIR, poverty-income ratio; SBP, systolic blood pressure.

## Introduction

A high-quality dietary pattern provides essential nutrients to promote health within energy requirements by balancing intakes of a variety of nutrient-rich foods and limiting empty calorie sources. A commonly used tool to assess diet quality is the Healthy Eating Index (HEI), which scores dietary alignment with the Dietary Guidelines for Ameri-

cans (DGA). Higher HEI scores—representing better adherence to the guidelines—have been prospectively associated with lower incident cardiovascular disease (CVD) (1), type 2 diabetes (2), and all-cause, CVD, and cancer mortality in US adults (1–4).

The most recent version, HEI-2015, is calculated as the sum of 13 individually scored components that assess alignment with specific recommendations in the 2015–2020 DGA to consume or limit certain

foods and/or nutrients (5). Components are generally weighted equally at a maximum of 10 points each, with some components (vegetables, fruits, and proteins) divided into smaller 5-point subgroups, to represent importance of all dietary recommendations (5). Component scores sum to a maximum of 100 points for a diet that fully aligns with recommendations. Moderate HEI-2015 scores could indicate moderate alignment with guidelines on all components or full alignment with some and complete misalignment (0 score) with others. Examination of the component scores that comprise individuals' total HEI scores is recommended to better understand the dietary pattern represented by the summative scores (6). However, associations between diet quality and disease risk are typically investigated using only the total HEI-2015 score, which obscures any differences in the strength of associations with particular dietary components (7). Given the diverse nutrient and bioactive profiles of the foods that make up each HEI-2015 component, associations with cardiometabolic disease risk likely differ by component, such that adherence to particular dietary recommendations more strongly explains the diet–disease relation. To the authors' knowledge, the independent associations between individual HEI-2015 components and cardiometabolic risk factors have not yet been evaluated.

Furthermore, one of the components, Fatty Acids, is a composite score representing the ratio of unsaturated fatty acids to SFAs. The standard for a maximum score (10 points) is a ratio of  $\geq 2.5$ , whereas a ratio of  $\leq 1.2$  receives zero points, regardless of the types of unsaturated fats (monounsaturated vs. polyunsaturated) consumed. The physiological effects of fatty acids vary by type, with the greatest atherogenic lipid-lowering and coronary heart disease risk reductions resulting from replacement of saturated fats with polyunsaturated fats (8–10). Yet, under the HEI-2015 scoring criteria, monounsaturated and polyunsaturated fats are valued equally. Thus, the differences in fat subtype intakes that underlie differences in Fatty Acids component scores in the population should be assessed to better understand associations between this HEI component and cardiometabolic health.

Understanding which foods and nutrients contribute most to higher diet quality scores, and how they are associated with risk factors for cardiometabolic diseases, can guide policies and interventions to improve Americans' diets and help protect against such diseases. Therefore, the goals of this study were as follows: 1) to describe the differences in component scores that distinguish higher versus lower quality diets as scored by the HEI-2015, 2) quantify intakes of dietary fats (saturated, monounsaturated, and polyunsaturated) that comprise the Fatty Acids component scores, and 3) determine the associations between HEI-2015 component scores and cardiometabolic risk factors in US adults using data from the NHANES 2001–2016.

## Methods

### Study overview, study population, and analytic sample

Data from adults  $\geq 19$  y of age ( $n = 46,236$ ) participating in NHANES 2001–2016 were used after the exclusion of individuals who did not provide a reliable in-person dietary recall ( $n = 5008$ ) and pregnant or lactating females ( $n = 1547$ ), for a final analytic sample of  $n = 39,799$ . A description of NHANES and analytical methods is available online (11, 12). Use of human subjects for NHANES has been approved by

the National Center for Health Statistics Research Ethics Review Board and subjects consented to participate (13). Since the current study was a secondary data analysis lacking personal identifiers, additional institutional review board approval was not required.

### Sample characteristics

Demographic and lifestyle characteristics were self-reported and included age, gender, race/ethnicity (Mexican American, other Hispanic, non-Hispanic White, non-Hispanic Black, and other), family income-to-poverty guideline ratio [poverty-income ratio (PIR);  $< 1.35$ ,  $1.35$  to  $1.85$ , and  $> 1.85$ ], physical activity (sedentary, moderate, and vigorous as developed from questionnaire responses), and smoking status (current, former, and never). Use of antihypertension, lipid-lowering, and hypoglycemic medications was self-reported (14).

### Dietary intake data

Dietary data were based on a single 24-h dietary recall collected in person using the automated multiple-pass method (15). Detailed descriptions of the dietary recalls and data collection are available in the NHANES dietary data documentation (16). Energy and nutrient intakes from foods were determined using the Food and Nutrient Database for Dietary Studies (FNDDS) appropriate for each NHANES cycle (17), which are available from total nutrient intake files in the NHANES datasets. Food components (total vegetables, total fruit, etc.) and added sugars were determined using the USDA MyPyramid Patterns Equivalent Databases (for NHANES 2001–2004) and relevant Food Patterns Equivalent Databases for later NHANES cycles (18).

HEI-2015 scores were calculated for each person individually according to the simple scoring method, using an SAS program available on the website of the National Cancer Institute (19). Nine components score the adequacy of intakes for foods that are encouraged (Total Fruits, Whole Fruits, Total Vegetables, Greens and Beans, Whole Grains, Dairy, Total Protein Foods, Seafood and Plant Proteins, and Fatty Acids). The remaining 4 components (Refined Grains, Sodium, Added Sugars, and Saturated Fats) assess moderation, awarding maximum points for intakes that are at or below recommended limits. Detailed information on the development of the components, scoring standards, and density approach for the HEI-2015 has been described previously (4, 5, 20, 21). The construct validity, reliability, and criterion validity of the HEI-2015 have been established (4).

### Body-weight and laboratory parameters

Height, weight, and waist circumference were obtained according to NHANES protocols (22). BMI was calculated as body weight (kilograms) divided by height (meters) squared. Systolic and diastolic blood pressures were determined using standard NHANES protocols (23). Laboratory methods for measuring total cholesterol, HDL cholesterol, LDL cholesterol, triglycerides, fasting blood glucose, and fasting insulin are detailed online (24). HOMA-IR was calculated as plasma insulin (mU/L)  $\times$  plasma glucose (mmol/L)/22.5 (25).

### Statistical analyses

Analyses were adjusted for the complex sampling design of NHANES and incorporated appropriate sample weights as advised by the NHANES analytical guidelines (12). All analyses were performed using SAS release 9.4 (SAS Institute) (26). Subjects were divided into

quartiles based on total HEI scores and each component score (for 2 component scores, Greens and Beans and Total Protein Foods, only 3 groups could be created). Means/percentages and SEs of demographic data and total HEI and component scores by quartiles of total HEI score were determined. Regression analyses were used to assess whether total HEI scores and component scores were associated with body weight and laboratory parameters. Covariates in regression models included age; sex; race/ethnicity; family PIR; physical activity level; current smoking status; use of medications to lower blood pressure, lipids, or glucose; and BMI (excluding models for BMI and waist circumference). Further adjustment for total energy intake (kilocalories per day) did not substantively alter estimates and, thus, was not included in the final model. Least-squares means and SEs were output for quartiles of total HEI scores and component scores. Separate regression analyses were conducted to assess the intake of fat type (i.e., saturated, monounsaturated, and polyunsaturated) across quartiles of the HEI Fatty Acids component scores. A *P* value < 0.01 was considered significant.

## Results

### Sample characteristics

The mean total HEI-2015 scores in quartiles 1, 2, 3, and 4 were 33.82, 45.27, 54.42, and 68.37, respectively (Table 1). Adults with higher quality diets were, on average, older and reported higher family incomes relative to the poverty line; greater use of medications for lowering blood pressure, lipids, and glucose; greater physical activity; and lower smoking rates, compared with those with lower quality diets. The proportion of adults who identified as non-Hispanic Black or Mexican American declined across increasing total HEI-2015 score.

### Diet quality: total and component scores

The mean HEI-2015 score was  $50.47 \pm 0.17$  (median:  $49.75 \pm 0.20$ ). All individual component scores increased significantly with total HEI-2015 score (all *P* < 0.001) (Figure 1A; Supplemental Table 1). Across the range of total HEI-2015 scores, components related to fat and grain quality exhibited the greatest differences. Each 1-point higher HEI-2015 score was linearly associated with a 0.12-point greater Fatty Acids component score, indicating greater consumption of unsaturated fats relative to saturated fats, and a 0.12-point greater Whole Grains component score, indicating greater consumption of whole grains. Each 1-point higher HEI-2015 score was also associated with a 0.11-point greater score for Saturated Fats and Refined Grains, indicating lower intakes of these foods/nutrients. In contrast, the Dairy and Total Protein Foods components changed least (0.02 point) per 1-point higher total HEI-2015 score. Expressed as percentages of maximum component scores, Total Fruits and Whole Fruits exhibited the greatest variation across the distribution of total HEI-2015 scores, while Dairy and Total Protein Foods varied least (Figure 1B).

### Fat-composition differences underlying the Fatty Acids component score

The mean Fatty Acids component score was  $4.97 \pm 0.03$  (out of maximum of 10). Each 1-point greater Fatty Acids score was associated with 1.7-g lower saturated fat intake and 1.2-g greater intake of polyunsatu-

**TABLE 1** Demographic and lifestyle characteristics by quartile of HEI-2015 scores in nonpregnant, nonlactating US adults aged  $\geq 19$  y in NHANES 2001–2016<sup>1</sup>

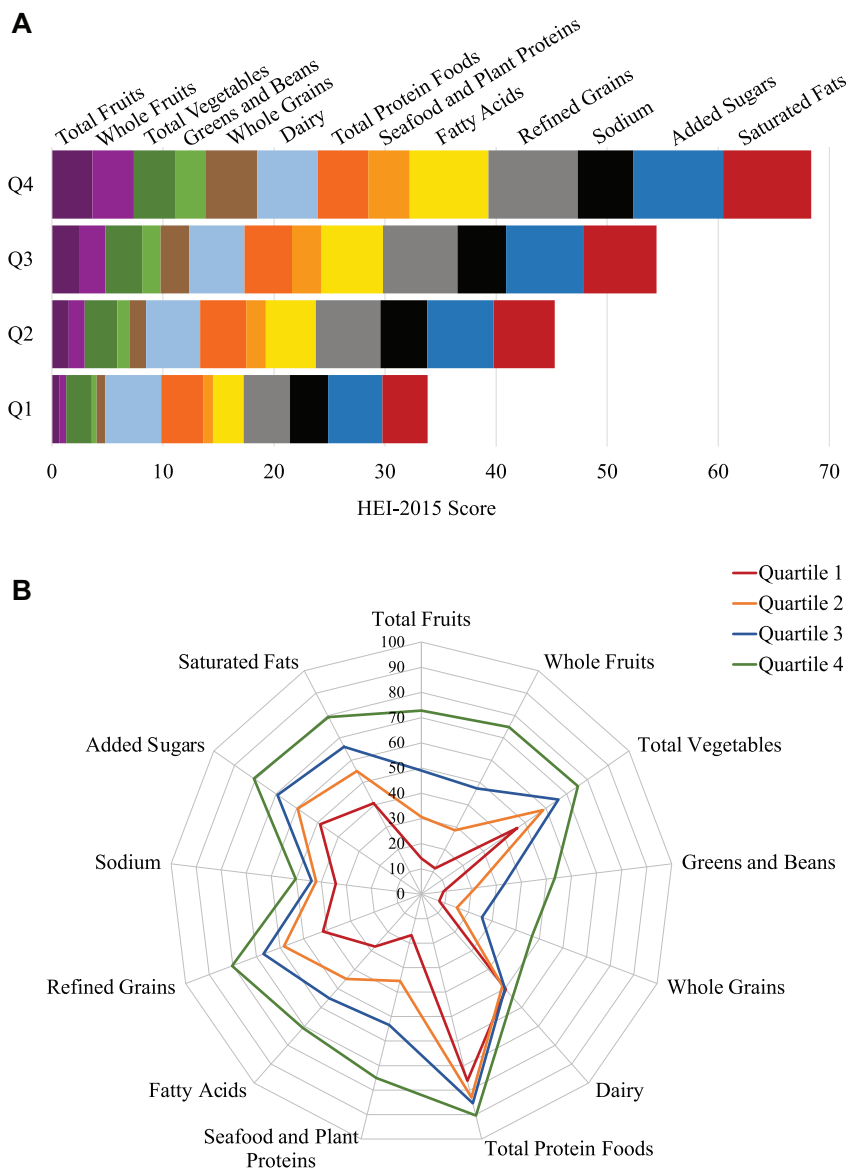
	HEI-2015 quartiles			
	Q1	Q2	Q3	Q4
Unweighted <i>n</i>	9945	10,018	10,071	9765
Mean HEI	33.82	45.27	54.42	68.37
Sex, %				
Male	52.5	50.9	49.6	44.2
Female	47.5	49.1	50.4	55.8
Age, y	43	46	48	52
Race/ethnicity, %				
Non-Hispanic White	68.8	67.9	68.3	70.9
Non-Hispanic Black	13.2	12.8	11.0	8.3
Mexican American	8.3	8.6	8.8	7.2
Other Hispanic	4.7	4.9	5.1	5.2
Other race	5.0	5.8	6.8	8.3
Poverty-income ratio, %				
<1.35	29.2	24.4	22.5	16.4
1.35–1.85	10.3	10.0	10.0	8.7
>1.85	60.5	65.6	67.5	74.9
Antihypertensive medication, %				
Yes	22.9	25.5	28.0	31.0
No	77.0	74.5	72.0	69.0
Lipid-lowering medication, %				
Yes	13.3	15.8	16.9	20.1
No	86.7	84.2	83.1	79.9
Hypoglycemic medication, %				
Yes	6.8	7.3	8.6	8.5
No	93.2	92.7	91.4	91.5
Physical activity, %				
Sedentary	29.0	28.3	26.0	20.9
Moderate	33.0	35.3	35.5	37.0
Vigorous	38.0	36.4	38.5	42.1
Smoking, %				
Current	30.5	24.4	18.6	9.9
Former	44.6	48.7	53.1	58.1
Never	24.7	26.7	28.2	32.0

<sup>1</sup>Percentages are survey weighted. HEI, Healthy Eating Index; Q, quartile.

rated fat (Table 2), which was mostly linoleic acid (18:2n–6; 1.1 g/point). Monounsaturated fat intake was 0.2-g greater per point. The leading food sources of these fats differed for individuals with the highest, versus lowest, quartile of Fatty Acids component scores (Supplemental Table 2). For the highest quartile, nuts and seeds were the primary sources of all fat types. Salad dressings and vegetable oils were also major sources of polyunsaturated fats in the highest quartile. In the lowest quartile of Fatty Acids component scores, pizza was the leading source of both polyunsaturated and monounsaturated fats, while cheese was the top source of saturated fat and closely followed pizza as a major source of monounsaturated fats.

### Associations between total diet quality and cardiometabolic risk factors

Diet quality was significantly associated with several cardiometabolic risk factors, after adjustment for demographic factors and health behaviors. Total HEI-2015 scores were inversely associated with BMI, waist circumference, systolic blood pressure (SBP), LDL cholesterol, triglycerides, glucose, and insulin and were associated with greater HDL cholesterol (all *P* < 0.01) (Table 3). These risk factors were carried



**FIGURE 1** Mean component scores by quartile of total HEI-2015 scores in nonpregnant, nonlactating US adults aged  $\geq 19$  y in NHANES 2001–2016 (A) and expressed as percentages of maximum possible component scores (B). HEI, Healthy Eating Index; Q, quartile.

forth to determine associations between individual HEI-2015 component scores and cardiometabolic risk.

### Associations between individual diet quality components and cardiometabolic risk factors

#### Adiposity measures.

All components except for Dairy, Total Protein Foods, and Added Sugars were inversely associated with either BMI, waist circumference, or both measures of body composition (Tables 4 and 5). The greatest incremental differences in BMI and waist circumference were observed for the Total Fruits component score [BMI (in  $\text{kg}/\text{m}^2$ ):  $-0.27$  per point,  $P < 0.001$ ; waist circumference:  $-0.71$  cm per point,  $P < 0.001$ ], followed by the Whole Fruits component (BMI:  $-0.23$  per point,

$P < 0.001$ ; waist circumference:  $-0.59$  cm per point,  $P < 0.001$ ). In contrast, greater Total Protein Foods scores were associated with higher BMI (0.17 per point,  $P < 0.001$ ) and waist circumference (0.28 cm per point,  $P = 0.005$ ).

#### Blood pressure.

SBP differed most with increasing Seafood and Plant Proteins component scores ( $-0.22$  mm Hg per point,  $P < 0.001$ ). Whole Fruits ( $-0.15$  mm Hg per point,  $P = 0.009$ ), Whole Grains ( $-0.14$  mm Hg per point,  $P < 0.001$ ), and Refined Grains ( $-0.09$  mm Hg per point,  $P = 0.006$ ) components were also significantly associated with lower SBP.

**TABLE 2** Mean fat intakes by quartile of Fatty Acids component scores in nonpregnant, nonlactating US adults aged  $\geq 19$  y in NHANES 2001–2016<sup>1</sup>

	Fatty Acids component score quartiles				Linear trend	
	Q1	Q2	Q3	Q4	$\beta \pm SE$	P
Fatty Acids score <sup>2</sup>	0.43 $\pm$ 0.01	3.12 $\pm$ 0.01	6.47 $\pm$ 0.02	9.87 $\pm$ 0.005		
Total fat, g	81.7 $\pm$ 0.7	86.4 $\pm$ 0.7	84.3 $\pm$ 0.6	77.7 $\pm$ 0.8	–0.5 $\pm$ 0.09	<0.001
Saturated fat, g	34.3 $\pm$ 0.3	30.2 $\pm$ 0.2	25.4 $\pm$ 0.2	18.2 $\pm$ 0.2	–1.7 $\pm$ 0.03	<0.001
Monounsaturated fat, g	27.4 $\pm$ 0.3	31.3 $\pm$ 0.3	31.3 $\pm$ 0.2	29.4 $\pm$ 0.3	0.2 $\pm$ 0.04	<0.001
Polyunsaturated fat, g	12.2 $\pm$ 0.1	17.0 $\pm$ 0.1	20.2 $\pm$ 0.2	23.6 $\pm$ 0.2	1.2 $\pm$ 0.02	<0.001
Linoleic acid, g	10.6 $\pm$ 0.1	15.0 $\pm$ 0.1	17.9 $\pm$ 0.2	21.0 $\pm$ 0.2	1.1 $\pm$ 0.02	<0.001

<sup>1</sup>Values are means  $\pm$  SEs. Q, quartile.

<sup>2</sup>Scored out of a maximum of 10 points, based on the ratio of total unsaturated fats (monounsaturated and polyunsaturated) to saturated fats.

### Lipid concentrations.

Higher scores for the Saturated Fats component (indicating lower percentages of calories consumed from saturated fat) were associated with lower LDL cholesterol. Several components were associated with HDL cholesterol. Higher scores for Added Sugars (indicating lower percentages of calories consumed from added sugars) were associated with the greatest differences in HDL cholesterol (0.66 mg/dL per point,  $P < 0.001$ ; to convert cholesterol to mmol/L, multiply by 0.0259), followed by Total Protein Foods (0.44 mg/dL per point,  $P < 0.001$ ). Lower triglycerides were observed with greater scores for Seafood and Plant Proteins (–1.89 mg/dL per point,  $P = 0.003$ ; to convert triglycerides to mmol/L, multiply by 0.0113), Greens and Beans (–1.55 mg/dL per point,  $P = 0.003$ ), and Added Sugars (–1.19 mg/dL per point,  $P = 0.002$ ), whereas greater scores for Saturated Fats were associated with higher triglycerides (1.15 mg/dL per point,  $P < 0.001$ ).

### Glycemic measures.

Higher scores for Whole Fruits were associated with lower fasting plasma glucose (–0.28 mg/dL per point,  $P = 0.009$ ; to convert glucose to mmol/L, multiply by 0.0555). Higher scores for Added Sugars were associated with the greatest differences in fasting insulin (–0.31  $\mu$ U/mL,  $P = 0.005$ ; to convert insulin to pmol/L, multiply by 6). Higher Total Fruits (–0.19  $\mu$ U/mL per point,  $P = 0.006$ ) and Whole Fruits (–0.19  $\mu$ U/mL per point,  $P = 0.002$ ) component scores were also associated with lower fasting insulin.

**TABLE 3** Cardiometabolic risk factors by quartile of HEI-2015 in nonpregnant, nonlactating US adults aged  $\geq 19$  y in NHANES 2001–2016<sup>1</sup>

	HEI-2015 quartiles				Linear trend	
	Q1	Q2	Q3	Q4	$\beta \pm SE$	P
BMI, kg/m <sup>2</sup>	29.51 $\pm$ 0.12	28.97 $\pm$ 0.10	28.55 $\pm$ 0.10	27.68 $\pm$ 0.08	–0.05 $\pm$ 0.003	<0.001
Waist circumference, cm	100.19 $\pm$ 0.27	98.97 $\pm$ 0.24	97.83 $\pm$ 0.25	95.66 $\pm$ 0.19	0.13 $\pm$ 0.01	<0.001
SBP, mm Hg	123.14 $\pm$ 0.29	122.64 $\pm$ 0.25	122.25 $\pm$ 0.23	121.90 $\pm$ 0.24	–0.04 $\pm$ 0.01	<0.001
DBP, mm Hg	71.27 $\pm$ 0.22	71.25 $\pm$ 0.19	71.11 $\pm$ 0.21	70.84 $\pm$ 0.23	–0.01 $\pm$ 0.01	0.18
Total cholesterol, mg/dL	196.59 $\pm$ 0.57	197.68 $\pm$ 0.60	196.72 $\pm$ 0.70	195.14 $\pm$ 0.66	–0.06 $\pm$ 0.02	0.02
LDL-C, mg/dL	116.51 $\pm$ 0.77	116.45 $\pm$ 0.73	115.79 $\pm$ 0.78	113.90 $\pm$ 0.82	–0.09 $\pm$ 0.03	0.005
HDL-C, mg/dL	51.47 $\pm$ 0.24	52.62 $\pm$ 0.23	53.33 $\pm$ 0.26	54.81 $\pm$ 0.24	0.10 $\pm$ 0.01	<0.001
Triglycerides, mg/dL	137.84 $\pm$ 2.24	135.07 $\pm$ 2.37	136.58 $\pm$ 2.80	128.60 $\pm$ 1.88	–0.20 $\pm$ 0.08	0.009
Glucose, mg/dL	105.97 $\pm$ 0.48	105.55 $\pm$ 0.49	104.24 $\pm$ 0.46	104.49 $\pm$ 0.58	–0.05 $\pm$ 0.02	0.009
Insulin, $\mu$ U/mL	13.76 $\pm$ 0.27	13.19 $\pm$ 0.27	12.93 $\pm$ 0.29	12.65 $\pm$ 0.20	–0.03 $\pm$ 0.01	0.001
HOMA-IR	3.89 $\pm$ 0.10	3.70 $\pm$ 0.10	3.56 $\pm$ 0.09	3.61 $\pm$ 0.09	–0.01 $\pm$ 0.004	0.02

<sup>1</sup>Values are means  $\pm$  SEs. Covariates include age, gender, race/ethnicity, poverty-income ratio, physical activity level, current smoking status, antihypertensive medication, lipid-lowering medication, hypoglycemic medication, and BMI (excluding models for BMI and waist circumference). DBP, diastolic blood pressure; HDL-C, HDL cholesterol; HEI, Healthy Eating Index; LDL-C, LDL cholesterol; Q, quartile; SBP, systolic blood pressure.

### Associations between unscored diet quality components and cardiometabolic risk factors

The mean score in the highest quartile of some components was at or near the maximum score. To ensure that truncation at upper score values did not prevent detection of associations, associations between the dietary factors represented by these components in unscored units of intake (actual cup-equivalents, ounce-equivalents, grams, or % of energy rather than component subscores) and risk factors were also assessed (Supplemental Table 3). Unlike HEI component scores, intakes were not expressed in relation to energy intake (i.e., per 1000 kcal or as a % of energy); thus, models were additionally adjusted for total energy intake. Most associations were confirmed, although in the opposite direction for moderation components (as would be expected), since these are reverse scored when calculating HEI scores. In addition, greater fatty acid ratios (ratio of unsaturated to saturated fat) were inversely associated with LDL cholesterol ( $\beta = -1.43$ ,  $P = 0.003$ ).

### Discussion

Among US adults in 2001–2016, higher versus lower quality diets scored by the HEI-2015 were primarily distinguished by higher scores for components that represent dietary fat and grain quality. Specifically, higher Fatty Acids component scores represented greater intakes of polyunsaturated fats and lower intakes of saturated fat, whereas monounsaturated fats varied minimally across the range of scores. Higher com-

**TABLE 4** Mean cardiometabolic risk factors by quartiles of HEI-2015 adequacy component scores in nonpregnant, nonlactating US adults aged  $\geq 19$  y in NHANES 2001–2016<sup>1</sup>

	Component score quartiles				Linear trend	
	Q1	Q2	Q3	Q4	$\beta \pm SE$	P
Total Fruit (5 <sup>2</sup> )	0.01 $\pm$ 0.002	0.49 $\pm$ 0.01	2.93 $\pm$ 0.02	4.98 $\pm$ 0.002		
BMI, kg/m <sup>2</sup>	29.49 $\pm$ 0.09	28.84 $\pm$ 0.12	28.33 $\pm$ 0.11	27.92 $\pm$ 0.11	−0.27 $\pm$ 0.02	<0.001
Waist circumference, cm	100.22 $\pm$ 0.23	98.61 $\pm$ 0.28	97.36 $\pm$ 0.25	96.14 $\pm$ 0.23	−0.71 $\pm$ 0.05	<0.001
Systolic blood pressure, mm Hg	122.76 $\pm$ 0.25	122.33 $\pm$ 0.26	122.55 $\pm$ 0.26	122.22 $\pm$ 0.28	−0.08 $\pm$ 0.06	0.18
LDL-C, mg/dL	117.27 $\pm$ 0.64	115.69 $\pm$ 0.90	114.20 $\pm$ 0.72	115.15 $\pm$ 0.83	−0.36 $\pm$ 0.17	0.04
HDL-C, mg/dL	53.21 $\pm$ 0.22	53.14 $\pm$ 0.24	52.60 $\pm$ 0.21	53.25 $\pm$ 0.26	−0.03 $\pm$ 0.06	0.58
Triglycerides, mg/dL	136.01 $\pm$ 2.31	132.21 $\pm$ 1.92	133.36 $\pm$ 2.32	136.01 $\pm$ 2.25	0.16 $\pm$ 0.58	0.78
Glucose, mg/dL	105.78 $\pm$ 0.53	105.18 $\pm$ 0.47	104.67 $\pm$ 0.49	104.49 $\pm$ 0.58	−0.25 $\pm$ 0.14	0.08
Insulin, $\mu$ U/mL	13.48 $\pm$ 0.30	13.55 $\pm$ 0.34	12.82 $\pm$ 0.22	12.64 $\pm$ 0.21	−0.19 $\pm$ 0.07	0.006
Whole Fruit (5)	0.00 $\pm$ 0.002	0.26 $\pm$ 0.004	2.60 $\pm$ 0.02	4.99 $\pm$ 0.002		
BMI, kg/m <sup>2</sup>	29.25 $\pm$ 0.08	28.63 $\pm$ 0.17	28.48 $\pm$ 0.12	27.99 $\pm$ 0.11	−0.23 $\pm$ 0.02	<0.001
Waist circumference, cm	99.64 $\pm$ 0.21	97.97 $\pm$ 0.41	97.66 $\pm$ 0.27	96.40 $\pm$ 0.25	−0.59 $\pm$ 0.05	<0.001
Systolic blood pressure, mm Hg	122.92 $\pm$ 0.21	122.70 $\pm$ 0.42	122.28 $\pm$ 0.27	121.94 $\pm$ 0.26	−0.15 $\pm$ 0.06	0.009
LDL-C, mg/dL	117.01 $\pm$ 0.59	112.75 $\pm$ 1.37	114.49 $\pm$ 0.88	115.24 $\pm$ 0.71	−0.23 $\pm$ 0.15	0.13
HDL-C, mg/dL	53.04 $\pm$ 0.18	52.72 $\pm$ 0.34	53.05 $\pm$ 0.26	53.17 $\pm$ 0.26	0.01 $\pm$ 0.05	0.79
Triglycerides, mg/dL	135.53 $\pm$ 1.91	130.15 $\pm$ 3.59	135.12 $\pm$ 2.62	133.79 $\pm$ 2.03	−0.10 $\pm$ 0.52	0.85
Glucose, mg/dL	105.78 $\pm$ 0.42	105.31 $\pm$ 1.06	104.71 $\pm$ 0.46	104.21 $\pm$ 0.42	−0.28 $\pm$ 0.11	0.009
Insulin, $\mu$ U/mL	13.48 $\pm$ 0.23	13.95 $\pm$ 0.75	12.91 $\pm$ 0.24	12.56 $\pm$ 0.19	−0.19 $\pm$ 0.06	0.002
Total Vegetables (5)	0.80 $\pm$ 0.01	2.43 $\pm$ 0.01	4.03 $\pm$ 0.01	4.99 $\pm$ 0.001		
BMI, kg/m <sup>2</sup>	28.79 $\pm$ 0.10	28.82 $\pm$ 0.10	28.65 $\pm$ 0.11	28.46 $\pm$ 0.12	−0.08 $\pm$ 0.03	<0.01
Waist circumference, cm	98.52 $\pm$ 0.25	98.49 $\pm$ 0.23	98.19 $\pm$ 0.28	97.51 $\pm$ 0.27	−0.21 $\pm$ 0.08	0.006
Systolic blood pressure, mm Hg	122.54 $\pm$ 0.22	122.79 $\pm$ 0.26	122.29 $\pm$ 0.26	122.32 $\pm$ 0.26	−0.07 $\pm$ 0.07	0.31
LDL-C, mg/dL	116.38 $\pm$ 0.86	114.67 $\pm$ 0.79	115.56 $\pm$ 0.66	116.04 $\pm$ 0.81	−0.16 $\pm$ 0.24	0.50
HDL-C, mg/dL	52.50 $\pm$ 0.21	53.00 $\pm$ 0.29	52.97 $\pm$ 0.22	53.71 $\pm$ 0.28	0.26 $\pm$ 0.07	<0.001
Triglycerides, mg/dL	137.02 $\pm$ 3.19	133.76 $\pm$ 1.99	132.44 $\pm$ 2.49	134.90 $\pm$ 2.54	−0.57 $\pm$ 0.80	0.48
Glucose, mg/dL	105.03 $\pm$ 0.50	105.71 $\pm$ 0.44	104.16 $\pm$ 0.44	105.33 $\pm$ 0.49	−0.02 $\pm$ 0.14	0.90
Insulin, $\mu$ U/mL	13.14 $\pm$ 0.23	13.19 $\pm$ 0.23	13.32 $\pm$ 0.33	12.91 $\pm$ 0.26	−0.04 $\pm$ 0.08	0.57
Greens and Beans (5)	0.00 $\pm$ 0.0004	— <sup>3</sup>	2.00 $\pm$ 0.03	4.93 $\pm$ 0.003		
BMI, kg/m <sup>2</sup>	28.85 $\pm$ 0.08	— <sup>3</sup>	28.58 $\pm$ 0.16	28.28 $\pm$ 0.11	−0.10 $\pm$ 0.02	<0.001
Waist circumference, cm	98.61 $\pm$ 0.19	— <sup>3</sup>	97.70 $\pm$ 0.35	97.28 $\pm$ 0.26	−0.26 $\pm$ 0.06	<0.001
Systolic blood pressure, mm Hg	122.71 $\pm$ 0.18	— <sup>3</sup>	121.86 $\pm$ 0.34	122.19 $\pm$ 0.25	−0.11 $\pm$ 0.05	0.03
LDL-C, mg/dL	115.88 $\pm$ 0.49	— <sup>3</sup>	115.87 $\pm$ 1.19	115.05 $\pm$ 0.80	−0.21 $\pm$ 0.18	0.23
HDL-C, mg/dL	52.52 $\pm$ 0.15	— <sup>3</sup>	53.73 $\pm$ 0.38	54.09 $\pm$ 0.26	0.31 $\pm$ 0.06	<0.001
Triglycerides, mg/dL	137.20 $\pm$ 1.71	— <sup>3</sup>	130.15 $\pm$ 3.96	129.89 $\pm$ 2.01	−1.55 $\pm$ 0.51	0.003
Glucose, mg/dL	105.46 $\pm$ 0.32	— <sup>3</sup>	104.67 $\pm$ 0.54	104.29 $\pm$ 0.54	−0.22 $\pm$ 0.12	0.08
Insulin, $\mu$ U/mL	13.15 $\pm$ 0.16	— <sup>3</sup>	13.15 $\pm$ 0.28	13.09 $\pm$ 0.26	0.00 $\pm$ 0.05	0.96
Whole Grains (10)	0.01 $\pm$ 0.002	0.32 $\pm$ 0.01	2.18 $\pm$ 0.01	7.29 $\pm$ 0.03		
BMI, kg/m <sup>2</sup>	28.94 $\pm$ 0.08	29.29 $\pm$ 0.32	28.52 $\pm$ 0.10	28.26 $\pm$ 0.10	−0.10 $\pm$ 0.02	<0.001
Waist circumference, cm	98.87 $\pm$ 0.21	99.41 $\pm$ 0.70	97.80 $\pm$ 0.24	97.07 $\pm$ 0.22	−0.25 $\pm$ 0.03	<0.001
Systolic blood pressure, mm Hg	122.80 $\pm$ 0.21	123.89 $\pm$ 0.73	122.40 $\pm$ 0.25	121.82 $\pm$ 0.25	−0.14 $\pm$ 0.04	<0.001
LDL-C, mg/dL	116.27 $\pm$ 0.62	113.58 $\pm$ 2.45	114.80 $\pm$ 0.74	115.62 $\pm$ 0.81	−0.16 $\pm$ 0.13	0.19
HDL-C, mg/dL	52.95 $\pm$ 0.21	52.97 $\pm$ 0.79	53.35 $\pm$ 0.24	52.98 $\pm$ 0.25	0.01 $\pm$ 0.04	0.78
Triglycerides, mg/dL	136.29 $\pm$ 1.89	132.77 $\pm$ 7.13	135.06 $\pm$ 2.26	130.85 $\pm$ 1.96	−0.71 $\pm$ 0.30	0.02
Glucose, mg/dL	105.74 $\pm$ 0.41	102.95 $\pm$ 1.08	104.65 $\pm$ 0.48	104.43 $\pm$ 0.52	−0.15 $\pm$ 0.08	0.08
Insulin, $\mu$ U/mL	13.24 $\pm$ 0.20	11.98 $\pm$ 0.70	13.22 $\pm$ 0.27	12.97 $\pm$ 0.23	−0.01 $\pm$ 0.04	0.83
Dairy (10)	0.77 $\pm$ 0.01	3.45 $\pm$ 0.01	6.43 $\pm$ 0.02	9.70 $\pm$ 0.01		
BMI, kg/m <sup>2</sup>	28.81 $\pm$ 0.10	28.70 $\pm$ 0.09	28.63 $\pm$ 0.12	28.58 $\pm$ 0.10	−0.03 $\pm$ 0.02	0.05
Waist circumference, cm	98.25 $\pm$ 0.25	98.22 $\pm$ 0.23	98.08 $\pm$ 0.26	98.14 $\pm$ 0.25	−0.02 $\pm$ 0.03	0.50
Systolic blood pressure, mm Hg	122.73 $\pm$ 0.25	122.32 $\pm$ 0.24	122.67 $\pm$ 0.21	122.21 $\pm$ 0.26	−0.04 $\pm$ 0.03	0.15
LDL-C, mg/dL	115.85 $\pm$ 0.76	115.54 $\pm$ 0.82	115.19 $\pm$ 0.81	116.10 $\pm$ 0.83	0.04 $\pm$ 0.12	0.74
HDL-C, mg/dL	53.24 $\pm$ 0.21	53.28 $\pm$ 0.23	52.90 $\pm$ 0.25	52.80 $\pm$ 0.26	−0.06 $\pm$ 0.03	0.07
Triglycerides, mg/dL	137.95 $\pm$ 3.22	133.82 $\pm$ 2.16	132.31 $\pm$ 2.12	134.20 $\pm$ 1.86	−0.29 $\pm$ 0.35	0.41
Glucose, mg/dL	105.67 $\pm$ 0.48	105.02 $\pm$ 0.50	104.86 $\pm$ 0.45	104.75 $\pm$ 0.48	−0.10 $\pm$ 0.07	0.15
Insulin, $\mu$ U/mL	13.05 $\pm$ 0.32	12.97 $\pm$ 0.25	13.26 $\pm$ 0.23	13.26 $\pm$ 0.22	0.02 $\pm$ 0.04	0.55
Total Protein Foods (5)	2.19 $\pm$ 0.01	4.33 $\pm$ 0.01	— <sup>4</sup>	5.00 $\pm$ 0.001		
BMI, kg/m <sup>2</sup>	28.39 $\pm$ 0.11	28.48 $\pm$ 0.11	— <sup>4</sup>	28.86 $\pm$ 0.09	0.17 $\pm$ 0.04	<0.001
Waist circumference, cm	97.71 $\pm$ 0.27	98.07 $\pm$ 0.27	— <sup>4</sup>	98.39 $\pm$ 0.20	0.28 $\pm$ 0.10	0.005
Systolic blood pressure, mm Hg	122.75 $\pm$ 0.27	122.49 $\pm$ 0.32	— <sup>4</sup>	122.37 $\pm$ 0.16	−0.11 $\pm$ 0.08	0.19

(Continued)

TABLE 4 (Continued)

	Component score quartiles				Linear trend	
	Q1	Q2	Q3	Q4	$\beta \pm SE$	P
LDL-C, mg/dL	115.52 ± 0.87	115.36 ± 0.92	— <sup>4</sup>	115.81 ± 0.50	0.26 ± 0.31	0.41
HDL-C, mg/dL	52.37 ± 0.27	52.94 ± 0.29	— <sup>4</sup>	53.38 ± 0.18	0.44 ± 0.10	<0.001
Triglycerides, mg/dL	134.55 ± 2.18	139.37 ± 2.99	— <sup>4</sup>	133.22 ± 1.72	−0.58 ± 0.86	0.50
Glucose, mg/dL	105.15 ± 0.49	104.90 ± 0.61	— <sup>4</sup>	105.09 ± 0.33	0.11 ± 0.19	0.58
Insulin, $\mu$ U/mL	13.01 ± 0.23	13.11 ± 0.28	— <sup>4</sup>	13.19 ± 0.17	0.12 ± 0.08	0.12
Seafood and Plant Proteins (5)	0.00 ± 0.001	0.64 ± 0.01	3.03 ± 0.02	5.00 ± 0.001		
BMI, kg/m <sup>2</sup>	29.11 ± 0.10	28.76 ± 0.17	28.54 ± 0.10	28.22 ± 0.09	−0.16 ± 0.02	<0.001
Waist circumference, cm	99.34 ± 0.22	98.20 ± 0.40	97.68 ± 0.24	97.07 ± 0.21	−0.40 ± 0.05	<0.001
Systolic blood pressure, mm Hg	122.96 ± 0.21	122.70 ± 0.39	122.37 ± 0.31	121.93 ± 0.22	−0.22 ± 0.05	<0.001
LDL-C, mg/dL	116.16 ± 0.68	114.96 ± 1.08	116.12 ± 1.00	115.15 ± 0.61	−0.23 ± 0.16	0.14
HDL-C, mg/dL	52.29 ± 0.18	52.51 ± 0.35	53.08 ± 0.26	54.08 ± 0.24	0.34 ± 0.05	<0.001
Triglycerides, mg/dL	138.88 ± 1.91	138.92 ± 4.09	130.76 ± 2.63	130.23 ± 2.07	−1.89 ± 0.51	<0.001
Glucose, mg/dL	105.60 ± 0.33	104.84 ± 0.77	104.37 ± 0.51	104.92 ± 0.42	−0.16 ± 0.09	0.08
Insulin, $\mu$ U/mL	13.21 ± 0.23	13.28 ± 0.31	13.15 ± 0.39	13.00 ± 0.17	−0.07 ± 0.05	0.11
Fatty Acids (10)	0.44 ± 0.01	3.12 ± 0.01	6.47 ± 0.02	9.87 ± 0.01		
BMI, kg/m <sup>2</sup>	28.74 ± 0.11	28.87 ± 0.11	28.65 ± 0.11	28.46 ± 0.10	−0.03 ± 0.01	0.01
Waist circumference, cm	98.60 ± 0.26	98.59 ± 0.26	98.07 ± 0.25	97.41 ± 0.24	−0.13 ± 0.03	<0.001
Systolic blood pressure, mm Hg	122.86 ± 0.29	122.44 ± 0.27	122.28 ± 0.23	122.35 ± 0.24	−0.06 ± 0.03	0.07
LDL-C, mg/dL	116.56 ± 0.78	116.26 ± 0.86	115.29 ± 0.82	114.56 ± 0.77	−0.24 ± 0.11	0.02
HDL-C, mg/dL	52.54 ± 0.23	52.65 ± 0.23	53.11 ± 0.21	53.93 ± 0.25	0.14 ± 0.03	<0.001
Triglycerides, mg/dL	137.22 ± 2.18	134.35 ± 2.29	136.64 ± 2.10	129.89 ± 2.75	−0.58 ± 0.31	0.07
Glucose, mg/dL	105.35 ± 0.46	105.54 ± 0.46	104.80 ± 0.44	104.60 ± 0.44	−0.10 ± 0.06	0.09
Insulin, $\mu$ U/mL	13.22 ± 0.23	13.41 ± 0.27	12.94 ± 0.25	12.97 ± 0.27	−0.03 ± 0.03	0.29

<sup>1</sup>Values are means ± SEs. Covariates include age, gender, ethnicity, poverty-income ratio, physical activity level, current smoking status, antihypertensive medication, lipid-lowering medication, hypoglycemic medication, and BMI (excluding models for BMI and waist circumference). HDL-C, HDL cholesterol; HEI, Healthy Eating Index; LDL-C, LDL cholesterol; Q, quartile.

<sup>2</sup>Maximum component score.

<sup>3</sup>Quartiles 1 and 2 were merged because estimated scores were equivalent.

<sup>4</sup>Quartiles 3 and 4 were merged because estimated scores were equivalent.

ponent scores were generally associated with better cardiometabolic health, although the Whole Fruits and Seafood and Plant Proteins components were most favorably associated with the assessed risk factors.

These findings partly align with a previous analysis that scored diet quality in adult participants in NHANES 2001–2008 using an earlier version of the HEI (27). Differences in total diet quality scored by HEI-2005 were primarily explained by a component that scored intakes of solid fats, alcohols, and added sugars (SoFAAS; scored out of 20 points; linear  $\beta = 0.40$ ,  $P = 0.0001$ ), which is most comparable to the Added Sugars and Saturated Fats components in HEI-2015 (5). The next greatest differences were in scores for the Oils component ( $\beta = 0.11$ ,  $P = 0.0001$ ), which is now encompassed by the Fatty Acids component, and Saturated Fats ( $\beta = 0.10$ ,  $P = 0.0001$ ). Thus, differences in fat quality contributed substantially to variation in total diet quality previously scored by the HEI-2005 and by its modern version, HEI-2015, in the present study. In contrast, differences in grain components were minor contributors to variation in total HEI-2005 scores (Whole Grains,  $\beta = 0.04$ ; Total Grains,  $\beta = 0.01$ ), whereas the HEI-2015 counterparts, Whole Grains and Refined Grains, were among the top components that explained differences in total diet quality. The HEI-2005 only allocated a maximum of 5 points for the Whole Grains component (which was increased to 10 points in subsequent versions) and scored intake of Total Grains (out of 5 points) but not Refined Grains. Changes in component definitions and relative weights in the total HEI-2015 score may account

for their greater contribution to total diet quality scores, compared with the HEI-2005.

While the Whole Grain component was among the leading contributors to higher HEI-2015 scores, it should be noted that the mean Whole Grains component score in the highest quartile of total diet quality (4.69) was still well below the maximum of 10. Whole Grains was also consistently the lowest scoring component (expressed as a percentage of maximum points) in all quartiles. In contrast, the mean Refined Grains score in the highest quartile was 80% of the maximum, indicating that adults with high diet quality are consuming fewer refined grains but still need to increase their intakes of whole grains.

The fat composition of most Americans adults' diets is also suboptimal. The mean Fatty Acids component score for those with the highest diet quality (quartile 4) was just 7.09 out of 10. Higher Fatty Acids scores can reflect greater intakes of monounsaturated and/or polyunsaturated fats, lower intakes of saturated fats, or both. On average, adults with higher Fatty Acids component scores had lower intakes of saturated fat and greater intakes of polyunsaturated fats, primarily linoleic acid. The dietary sources of these fats differed as well. Polyunsaturated fats were largely from nuts/seeds and vegetable oils (e.g., corn, soy, canola, olive, etc.) in those with the highest scores, while the leading source of polyunsaturated fats for those with low scores was pizza. As pizza is not a particularly rich source of polyunsaturated fat, its ranking as a major source for individuals with low Fatty Acids scores reflects the large quantity consumed and the relative shortage of healthier polyunsaturated-

**TABLE 5** Mean cardiometabolic risk factors by quartiles of HEI-2015 moderation component scores in nonpregnant, nonlactating US adults aged  $\geq 19$  y in NHANES 2001–2016<sup>1</sup>

	Component score quartiles				Linear trend	
	Q1	Q2	Q3	Q4	$\beta \pm SE$	P
Refined Grains (10 <sup>2</sup> )	0.85 $\pm$ 0.02	5.17 $\pm$ 0.02	8.50 $\pm$ 0.01	9.99 $\pm$ 0.002		
BMI, kg/m <sup>2</sup>	28.94 $\pm$ 0.11	28.60 $\pm$ 0.10	28.66 $\pm$ 0.11	28.54 $\pm$ 0.10	−0.04 $\pm$ 0.01	0.001
Waist circumference, cm	98.65 $\pm$ 0.27	97.95 $\pm$ 0.23	98.14 $\pm$ 0.26	97.96 $\pm$ 0.24	−0.06 $\pm$ 0.03	0.04
Systolic blood pressure, mm Hg	122.76 $\pm$ 0.29	122.92 $\pm$ 0.22	122.46 $\pm$ 0.24	121.88 $\pm$ 0.24	−0.09 $\pm$ 0.03	0.006
LDL-C, mg/dL	115.50 $\pm$ 0.67	115.60 $\pm$ 0.85	115.33 $\pm$ 0.82	116.14 $\pm$ 0.75	0.04 $\pm$ 0.08	0.68
HDL-C, mg/dL	52.11 $\pm$ 0.23	52.47 $\pm$ 0.22	53.34 $\pm$ 0.25	54.18 $\pm$ 0.24	0.22 $\pm$ 0.03	<0.001
Triglycerides, mg/dL	135.35 $\pm$ 2.06	134.64 $\pm$ 2.14	134.42 $\pm$ 2.75	133.83 $\pm$ 2.24	−0.18 $\pm$ 0.30	0.55
Glucose, mg/dL	104.73 $\pm$ 0.40	105.88 $\pm$ 0.46	104.89 $\pm$ 0.51	104.80 $\pm$ 0.44	−0.01 $\pm$ 0.06	0.82
Insulin, $\mu$ U/mL	13.25 $\pm$ 0.32	13.58 $\pm$ 0.25	12.96 $\pm$ 0.26	12.77 $\pm$ 0.20	−0.06 $\pm$ 0.04	0.13
Sodium (10)	0.01 $\pm$ 0.002	2.30 $\pm$ 0.01	5.62 $\pm$ 0.01	9.09 $\pm$ 0.02		
BMI, kg/m <sup>2</sup>	29.10 $\pm$ 0.11	28.88 $\pm$ 0.10	28.60 $\pm$ 0.11	28.12 $\pm$ 0.10	−0.10 $\pm$ 0.01	<0.001
Waist circumference, cm	98.93 $\pm$ 0.25	98.49 $\pm$ 0.23	98.17 $\pm$ 0.25	97.08 $\pm$ 0.25	−0.19 $\pm$ 0.03	<0.001
Systolic blood pressure, mm Hg	122.47 $\pm$ 0.26	122.64 $\pm$ 0.22	122.42 $\pm$ 0.27	122.40 $\pm$ 0.23	0.00 $\pm$ 0.03	0.97
LDL-C, mg/dL	115.45 $\pm$ 0.75	115.70 $\pm$ 0.84	115.74 $\pm$ 0.67	115.79 $\pm$ 0.88	0.05 $\pm$ 0.12	0.68
HDL-C, mg/dL	53.10 $\pm$ 0.23	53.26 $\pm$ 0.24	52.71 $\pm$ 0.27	53.16 $\pm$ 0.24	−0.01 $\pm$ 0.03	0.68
Triglycerides, mg/dL	136.80 $\pm$ 2.65	127.87 $\pm$ 1.85	134.22 $\pm$ 2.18	139.38 $\pm$ 2.87	0.50 $\pm$ 0.37	0.19
Glucose, mg/dL	105.43 $\pm$ 0.53	104.91 $\pm$ 0.47	105.01 $\pm$ 0.48	104.94 $\pm$ 0.47	−0.03 $\pm$ 0.07	0.66
Insulin, $\mu$ U/mL	13.06 $\pm$ 0.29	13.27 $\pm$ 0.26	13.25 $\pm$ 0.23	12.96 $\pm$ 0.23	−0.01 $\pm$ 0.03	0.73
Added Sugars (10)	1.30 $\pm$ 0.02	5.76 $\pm$ 0.01	8.71 $\pm$ 0.01	9.98 $\pm$ 0.002		
BMI, kg/m <sup>2</sup>	28.77 $\pm$ 0.11	28.74 $\pm$ 0.12	28.43 $\pm$ 0.11	28.76 $\pm$ 0.10	−0.02 $\pm$ 0.02	0.18
Waist circumference, cm	98.55 $\pm$ 0.28	98.20 $\pm$ 0.28	97.47 $\pm$ 0.25	98.38 $\pm$ 0.23	−0.07 $\pm$ 0.04	0.05
Systolic blood pressure, mm Hg	122.34 $\pm$ 0.26	122.40 $\pm$ 0.26	122.26 $\pm$ 0.26	122.90 $\pm$ 0.27	0.05 $\pm$ 0.03	0.18
LDL-C, mg/dL	116.81 $\pm$ 0.86	115.65 $\pm$ 0.80	115.07 $\pm$ 0.73	115.15 $\pm$ 0.86	−0.18 $\pm$ 0.13	0.18
HDL-C, mg/dL	49.94 $\pm$ 0.22	52.18 $\pm$ 0.19	54.16 $\pm$ 0.24	55.81 $\pm$ 0.28	0.66 $\pm$ 0.03	<0.001
Triglycerides, mg/dL	139.83 $\pm$ 2.68	137.69 $\pm$ 2.71	130.64 $\pm$ 2.36	130.13 $\pm$ 2.09	−1.19 $\pm$ 0.38	0.002
Glucose, mg/dL	104.88 $\pm$ 0.51	104.13 $\pm$ 0.38	104.08 $\pm$ 0.44	106.99 $\pm$ 0.57	0.14 $\pm$ 0.07	0.06
Insulin, $\mu$ U/mL	13.74 $\pm$ 0.27	13.17 $\pm$ 0.21	12.83 $\pm$ 0.23	12.80 $\pm$ 0.29	−0.10 $\pm$ 0.04	0.004
Saturated Fats (10)	1.06 $\pm$ 0.02	4.97 $\pm$ 0.01	8.09 $\pm$ 0.01	9.98 $\pm$ 0.002		
BMI, kg/m <sup>2</sup>	29.33 $\pm$ 0.12	28.92 $\pm$ 0.10	28.38 $\pm$ 0.10	28.07 $\pm$ 0.10	−0.14 $\pm$ 0.02	<0.001
Waist circumference, cm	99.84 $\pm$ 0.27	98.81 $\pm$ 0.23	97.48 $\pm$ 0.24	96.51 $\pm$ 0.22	−0.37 $\pm$ 0.03	<0.001
Systolic blood pressure, mm Hg	122.61 $\pm$ 0.24	122.06 $\pm$ 0.25	122.67 $\pm$ 0.21	122.60 $\pm$ 0.26	0.02 $\pm$ 0.03	0.42
LDL-C, mg/dL	117.15 $\pm$ 0.83	115.94 $\pm$ 0.75	114.76 $\pm$ 0.79	114.76 $\pm$ 0.85	−0.33 $\pm$ 0.12	0.006
HDL-C, mg/dL	53.30 $\pm$ 0.23	52.60 $\pm$ 0.26	53.26 $\pm$ 0.21	53.07 $\pm$ 0.27	−0.01 $\pm$ 0.03	0.69
Triglycerides, mg/dL	129.53 $\pm$ 2.41	134.27 $\pm$ 2.58	132.61 $\pm$ 2.11	142.05 $\pm$ 2.51	1.15 $\pm$ 0.33	<0.001
Glucose, mg/dL	106.15 $\pm$ 0.51	105.09 $\pm$ 0.44	104.59 $\pm$ 0.48	104.42 $\pm$ 0.49	−0.17 $\pm$ 0.07	0.01
Insulin, $\mu$ U/mL	13.42 $\pm$ 0.26	13.08 $\pm$ 0.20	13.08 $\pm$ 0.29	12.96 $\pm$ 0.31	−0.05 $\pm$ 0.03	0.16

<sup>1</sup>Values are means  $\pm$  SEs. Covariates include age, gender, ethnicity, poverty-income ratio, physical activity level, current smoking status, antihypertensive medication, lipid-lowering medication, hypoglycemic medication, and BMI (excluding models for BMI and waist circumference). HDL-C, HDL cholesterol; HEI, Healthy Eating Index; LDL-C, LDL cholesterol; Q, quartile.

<sup>2</sup>Maximum component score.

rich foods in their diets. High-fat dairy products, namely cheese and ice cream, were major sources of saturated fat in the lowest quartile of scores, while nuts and seeds were leading sources for the highest quartile. Comparatively minimal differences in monounsaturated fat intakes were observed across the range of Fatty Acids component scores.

While both mono- and polyunsaturated fats are recommended to replace saturated fats (28), the strongest evidence supports the cardioprotective effect of replacing saturated fat with polyunsaturated fats (8, 29). Thus, the observed replacement of saturated fats with mostly polyunsaturated fats in US adults with higher Fatty Acids component scores is consistent with authoritative recommendations. Population scores could be improved by encouraging consumption of nuts, seeds, and nontropical oils (e.g., corn, soybean, canola) in place of saturated fat sources.

The HEI scoring metric distributes points among components according to a priori–defined standards, to quantify alignment with guidelines rather than their associations with health (5). The recommendations that correspond to these components are all intended to promote general health; however, particular components were more strongly associated with cardiometabolic risk factors than others. The Whole Fruits and Seafood and Plant Proteins components were most favorably associated with cardiometabolic risk factors, considering both the number and strength of risk factors with which they were associated. Prospective observational studies support an inverse association between fruit intake and cardiovascular disease incidence and mortality (30), while plant proteins (31) and fish consumption (32) have been associated with lower risk of all-cause and cardiovascular mortality and are recommended to decrease atherosclerotic CVD risk (28, 33). The favorable associations between these components and cardiometabolic



risk factors are, therefore, consistent with previous research and current dietary recommendations. However, as this is a cross-sectional study, causation cannot be inferred from the observed associations. These dietary components may be markers of a healthy lifestyle and, thus, cluster with other unmeasured health-promoting behaviors or with other dietary components that explain the favorable associations with cardiometabolic risk. Whole Fruits and Seafood and Plant Proteins components have previously been shown to exhibit moderate correlations (0.46–0.56) with total HEI-2015 scores (4), although other components that were similarly correlated with total diet quality (e.g., Total Vegetables) were not associated with as many—or as strongly with—assessed cardiometabolic risk factors. Thus, the observed associations are likely not explained by the correlation of these components with total diet quality alone, but rather may be attributable to beneficial components in these foods (e.g., fruit polyphenols, seafood omega-3 fatty acids), their displacement of other less healthful foods, or their correlation with other health-promoting behaviors.

The 2 components that score dietary fat quality, Fatty Acids and Saturated Fats, were both associated with lower waist circumference but differed in their associations with other risk factors. Higher Fatty Acids component scores were associated with higher HDL cholesterol, while the Saturated Fats scores were inversely associated with LDL cholesterol and were unexpectedly associated with higher triglycerides. Replacement of saturated with polyunsaturated fat is associated with the greatest LDL-cholesterol reductions (8, 10). Given that higher Fatty Acids component scores were primarily composed of lower saturated and higher polyunsaturated fat, it is surprising that higher Fatty Acids component scores were not associated with LDL cholesterol. It is possible that truncation of scores at the maximum (10 points = ratio  $\geq 2.5$ ) attenuated the association to nonsignificance, as the unscored ratio was associated with LDL cholesterol in the expected direction. The heterogeneity in food sources underlying the calculation of the fatty acid ratio is another complicating factor, as certain foods contain bioactives that can affect LDL cholesterol independently of fatty acids. Oils, for example, vary widely in their effects on circulating lipid concentrations (34), which may be partly explained by variable phytosterol content (35, 36). Salad dressings and vegetable oils were among the leading contributors to unsaturated fat intakes. Thus, differences in specific types of oils within these broad categories (e.g., corn, soy, canola, olive) consumed by people with higher versus lower Fatty Acids component scores could explain why a significant association with LDL cholesterol was not observed.

The Saturated Fats component awards greater points for less saturated fat consumption as a percentage of total energy (maximum of 10 points =  $\leq 8\%$  kcal from saturated fat), regardless of the nutrient(s) replacing saturated fat. The physiological benefits of reducing saturated fat intake are dependent on the replacement nutrient, with the greatest atherogenic lipid-lowering achieved by replacement of saturated with polyunsaturated fats, while replacement of saturated fat with carbohydrates is associated with smaller LDL-cholesterol reductions and increased triglycerides (8). Failure to consider the replacement nutrient in Saturated Fats component scoring may explain why better scores for this component (i.e., lower intakes of saturated fat) were associated with higher triglycerides.

Dairy scores were not significantly associated with any cardiometabolic risk factors. This finding does not necessarily mean that dairy foods do not affect cardiometabolic risk, but rather that these risk

factors did not substantially differ across the range of observed Dairy component scores in this population. This might be due to the heterogeneous nutrient profiles of dairy foods (e.g., cheese, milk, yogurt) encompassed by this component or the limited variation in Dairy scores (on average, 0.14-point greater per quartile increase) across the total HEI-2015 score distribution.

Over the past 18 y, the quality of Americans' diets has not substantially improved, with mean total HEI-2015 scores increasing by just 2 points (37). This study may inform interventions to improve diet quality, as components that differ most across the distribution of total HEI-2015 scores may be more amenable to improvement. Closer study of the barriers and facilitators to adherence in individuals with the lowest and highest scores for these components, respectively, could potentially guide strategies to improve adherence in those with the poorest diet quality. In contrast, Dairy scores were consistently low ( $\sim 50\%$  of maximum), regardless of overall diet quality, and Sodium scores also differed little between the highest and lowest quartiles (difference of 1.6 points out of 10). These dietary components may be challenging to modify, perhaps due to physiological barriers to consumption (i.e., lactose intolerance) (38, 39), consumers' attitudes and beliefs (40, 41), and the food environment (42, 43), and require more complex solutions.

Strengths of this study include analysis of a large US sample with the application of appropriate survey procedures to obtain nationally representative estimates. Our examination of individual component scores yields valuable insights into how Americans are achieving better diet quality, as scored by the HEI-2015, and how the components individually relate to cardiometabolic health, which has recently been recommended to enhance understanding of the relation between diet quality and cardiovascular health (7). Further disaggregation of US adults' Fatty Acids scores into fat subtype intakes, and assessment of their food sources, uniquely provides insight into how Americans are achieving better or worse fat quality scores, which may inform guidance to shift intakes toward more healthful types and sources. However, these analyses are limited by use of self-reported dietary data (a single 24-h recall), which may be subject to measurement error. A single recall per person is regarded as sufficient to estimate population mean dietary intakes, under the assumption that a 24-h recall is an unbiased measure of true intake but does not accurately represent the distribution of usual intakes (44). However, an objective of this study was to relate HEI total and component scores to individual cardiometabolic risk factors. The preferred statistical methods for such analyses—the multivariate Markov chain Monte Carlo method followed by regression—are under development and, thus, the available methodology cited by the National Cancer Institute was applied (45). Data were aggregated from 8 cycles spanning 16 y, a period throughout which the DGA have been updated 3 times. Although much of the advice remains unchanged, temporal trends may have contributed to some of the observed variation in total and component scores (37). The cross-sectional design prohibits causal inferences regarding the associations between diet and risk factors, as the temporality and direction of associations cannot be established. Finally, analyses were adjusted for known demographic and lifestyle covariates, but residual or unmeasured confounding may have influenced the observed associations. Adherence to dietary guidelines likely clusters with other unmeasured behaviors and dietary components that may explain the associations with cardiometabolic risk factors.

In conclusion, higher quality diets, as assessed by the HEI-2015, in US adults are primarily distinguished by consumption of healthier fats (less saturated and more polyunsaturated) and grain-based foods (more whole and fewer refined grains), and adherence to particular dietary recommendations is favorably associated with cardiometabolic risk factors. However, the average diet quality is suboptimal, and thus future investigation of interventions at the individual, community, and policy levels is needed to improve diet quality of the population and decrease the risk of many chronic diseases. Interventions targeting specific dietary components that are most favorably associated with cardiometabolic risk—namely, whole fruits, seafood, and plant proteins—may have the greatest impact on US adults' health.

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