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Diet quality and diet patterns in relation to circulating cardiometabolic biomarkers

Byung-Joon Ko[a,b,c,*], **Kyung Hee Park**[a,d,*], **Sangah Shin**[e,*], **Lesya Zaichenko**[a], **Cynthia R Davis**[f], **Judith A Crowell**[f,g], **Hyojee Joung**[e], and **Christos S Mantzoros**[a,h]

[a]Division of Endocrinology, Diabetes, and Metabolism, Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, MA 02215, USA

[b]Department of Family Medicine, College of Medicine, Korea University, Seoul 136-705, Korea

[c]Total Healthcare Center, Kangbuk Samsung Hospital, Sungkyunkwan University School of Medicine, Seoul 100-742, Korea

[d]Department of Family Medicine, Hallym University Sacred Heart Hospital, Hallym University, Gyeonggi-do 431-070, Korea

[e]Institute of Health and Environment and the Division of Public Health Nutrition, Graduate School of Public Health, Seoul National University, Seoul 151-742, Korea

[f]Judge Baker Children's Center, Boston, MA 02120, USA

[g]Department of Psychiatry and Behavioral Science, Stony Brook University School of Medicine, Stony Brook, NY 11794, USA

[h]Section of Endocrinology, Boston VA Healthcare System, Harvard Medical School, Boston, MA 02130, USA

Abstract

Background & Aims—We examined the effects of diet quality and dietary patterns in relation to biomarkers of risk including leptin, soluble intracellular adhesion molecule 1 (sICAM-1), C-reactive protein (CRP), and irisin.

Corresponding author: Christos S Mantzoros, Harvard Medical School, JP9B52A, Boston, MA 02130, USA, Tel.: +1 617 667 8630; Fax: +1 617 667 8634;, cmantzor@bidmc.harvard.edu.
*These authors contributed equally to this paper.

Authors' contributions

CSM conceived and developed the overall research plan, and had primary responsibility for final content. BJK, KHP, SS, and CSM designed the research; LZ, CRD, and JAC conducted the research; BJK, KHP, SS, and HJ analyzed the data; BJK, KHP, and SS wrote the paper. All authors read and approved the final manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

Methods—We analyzed data from 196 adults cross-sectionally. Dietary patterns were identified by factor analysis and diet quality scores were generated using a validated food-frequency questionnaire.

Results—Both the alternate healthy eating index-2010 (AHEI-2010) and the Dietary Approaches to Stop Hypertension (DASH) scores were negatively related to CRP, even after controlling for body mass index and total energy intake. Similarly, the prudent diet pattern was negatively related to leptin, sICAM-1, and CRP, whereas the Western diet pattern showed positive associations with these markers; however, after adjusting for all confounders, the associations only remained significant for leptin and sICAM-1. Irisin was positively associated with DASH and the prudent diet after controlling for all confounders (standardized $\beta = 0.23$, $P = 0.030$; standardized $\beta = 0.25$, $P = 0.021$, respectively). Irisin showed positive associations with increasing fruit consumption, whereas the levels of irisin decreased as meat consumption increased.

Conclusions—Irisin was directly associated with healthy diet types and patterns. Further studies regarding these mechanisms are warranted.

Keywords

Diet quality; Dietary pattern; Leptin; Intracellular adhesion molecule-1; C-reactive protein; Irisin

Introduction

Adherence to a healthy diet type or pattern is known to be related to a reduction of cardiovascular disease (CVD) risk factors, morbidity, and mortality.[1,2] In nutritional epidemiology studies, several diet quality indices that are assessed using the alternate healthy eating index (AHEI) or the Mediterranean diet score, and diet patterns that are assessed using factor analysis of dietary intake, have been widely used to explore the links between diet quality or patterns and the morbidity of chronic diseases or mortality.

Certain adipokines and inflammatory biomarkers have been proposed to be mediators or present a link between diet type and CVD risk.[1] Leptin, a proinflammatory cytokine secreted by adipose tissue, is known to be associated with the regulation of food intake, energy metabolism, and the development of obesity.[3] In addition, biomarkers reflecting systemic inflammation such as soluble intracellular adhesion molecule 1 (sICAM-1) and C-reactive protein (CRP), have been shown to be related to CVD risk.[4,5] Irisin, a newly discovered myokine, is associated with the risk of metabolic syndrome and CVD.[6]

Although previous studies focusing on the relationship between adherence to healthy diet types or patterns and several biomarkers related to CVD have shown significant associations,[1,7] few studies have investigated the association between serum leptin concentrations and diet pattern, and their results have been inconsistent.[8-10] For irisin, only one study up to now has addressed the issue of dietary quality and irisin, and it presented a conclusion of no association.[11] Moreover, little is known about the relationship between AHEI-2010 or the Dietary Approaches to Stop Hypertension (DASH) scores and the biomarkers of risk for CVD. The association between the consumption of specific food items or groups such as dairy and alcohol and inflammatory biomarkers has also been inconsistent among studies,[12-14] though the intake of fruits, vegetables, legumes, and fish seems to be related to reduced inflammatory biomarker concentrations.[15,16]

Thus, we examined cross-sectionally, whether the quality of diet, assessed by the AHEI-2010 or DASH diet scores, and/or diet patterns, assessed by factor analysis as well as specific food items, were associated with adipokines and inflammatory marker concentrations. These included leptin, sICAM-1, CRP, and irisin, all of which have been linked with obesity and CVD.

Materials and Methods

Study design

This study was performed using data from 196 Caucasian and African American individuals recruited via advertisements in the Greater Boston area from 2009 to 2011. Participants with a history of stroke or myocardial infarction, diabetes mellitus, hepatitis, cirrhosis, dialysis, long-term steroid use, active IV drug use, current treatment for cancer, or active infection were excluded from the study. Adequate blood samples were unavailable for all participants; therefore, 186 samples were measured for leptin, 166 for sICAM-1, 160 for CRP, and 185 for irisin.

The study protocol was approved by the Institutional Review Board at Beth Israel Deaconess Medical Center Committee in accordance with the Helsinki Declaration. All individuals provided written informed consent. Participants' rights as research subjects, possible risks involved, and exceptions to confidentiality were clearly explained as part of the informed consent process.

Assessment of biomarkers

Fasting blood samples were obtained from participants then stored at −80 °C. Leptin was estimated by an RIA (Millipore. Billerica, MA, USA). sICAM-1 concentration was measured by a Quantikine ELISA (R&D Systems, Minneapolis, MN, USA). CRP concentration was determined with a Roche Cobas c311 clinical chemistry analyzer (Roche Diagnostics, Indianapolis, IN, USA). Irisin concentration was measured by colorimetric ELISA (Phoenix Pharmaceuticals, Burlingame, CA, USA). In this study, the inter- and intra-assay CVs were 3.6–6.2% and 0.01–8.3% for leptin, 4.4–6.7% and <15% for sICAM-1, 1.7–11.5% and 1.2– 3.6% for CRP, and <15% and <10% for irisin, respectively.[11]

Dietary assessment

Dietary intake data of the participants were collected using a validated self-administered Block FFQ (NutritionQuest, Berkeley, CA, USA). This FFQ contained validated questions about 110 food items, and the participants responded to each question following instruction from the study staff. The validity and reliability of the FFQ have both been previously described.[17]

Participants were asked about the average frequency and amount of each food item, which they had consumed during the past year. Response frequencies ranged from "never" to "every day." We obtained the intake of each food item by multiplying the frequency of the food by its pre-specified common serving size. The 110 food items were further categorized into food groups based on their nutritional properties and the culinary usage. Based on this categorization, we used 21 food groups to derive distinct dietary patterns by factor analysis, as previously described.[9]

Data from the FFQ were also used in the derivation of the AHEI-2010 and DASH scores. Details of the computation of these scores have been described elsewhere.[18,19] In summary,

the AHEI-2010, which is an updated diet quality index based on the original AHEI score, was assessed from the FFQ based on the following 11 food components: Vegetables, fruits, nuts and legumes, red meat and processed meats, sugar-sweetened beverages, alcohol, polyunsaturated fat, trans fat, ω-3 fat (eicosapentaenoic acid and docosahexaenoic acid), whole grains, and sodium intake.[18] The DASH diet score was calculated based on the following eight food components: Fruits, vegetables, nuts and legumes, low-fat dairy products, whole grains, sweets, red and processed meat, and sodium.[19]

Component scores were summed up to give the total AHEI-2010 score (ranged 0-110) and DASH diet score (ranged 8-40). The lowest score represents non-adherence and a higher score represents a higher adherence to each diet index.

Anthropometric and other measurements

Anthropometric and body composition data were measured by a registered dietician. Standing height was assessed to the nearest 0.1 cm. Body weight was measured with the use of a calibrated digital electric scale to the nearest 0.1 kg. Bioelectrical impedance analysis was assessed using a Quantum II bioelectrical impedance analyzer (RJL Systems, Clinton Township, MI, USA). These measurements were taken during the fasting state before the participant's blood was drawn, with participants wearing their standard clothing. Body mass index (BMI) was calculated as weight/height^2 (kg/m^2). Waist circumference (WC) was determined along the superior border of the iliac crest. Information of smoking status, alcohol consumption, physical activity, and other sociodemographic variables such as marriage, income, and education level was obtained through self-administered questionnaires.

Statistical analysis

To compare general characteristics according to gender and race, the χ^2 test for categorical variables and *t* test for continuous variables were used. To improve normality, logarithmic transformations were performed for non-normally distributed continuous variables. To derive dietary patterns, we carried out factor analysis (principal component analysis) using the daily intake of 21 food groups. The number of meaningful factors was determined by considering conventional criteria for principal component analysis: Eigenvalues, scree plot, variance explained, and interpretability. Using orthogonal rotation, we achieved a more easily interpretable structure and minimized the correlation between factors. For each dietary pattern and each subjects, a factor score was calculated by summing the standard intakes of each food or food groups weighted by their factor loading, and then standardized. Spearman's correlation analysis was performed between dietary indices, dietary pattern scores, and anthropometric measurements and biomarkers. To examine the relationship between dietary indices, dietary pattern scores, and biomarkers, multiple linear regression analysis was performed using the log-transformed biomarkers as dependent variables. In multiple linear regression analysis, potential confounders including age, gender, race, education, income, marriage, smoking, alcohol, exercise, BMI, total energy intake, and biomarkers were controlled for. Adjusted geometric means and standard errors of biomarker concentrations for each tertile group of intake, of each food group or item, were calculated by general linear models. Multiple linear regression analysis was used to test for linear trends across each tertile group. If there was a significant difference in the biomarker values between the tertile groups, a *post-hoc* test with Bonferroni method was used. All statistical analyses were performed using SAS (Version 9.3; SAS Institute, Cary, NC, USA) and a two-sided P value below 0.05 was regarded as statistically significant.

Results

General characteristics of the participants

Men were older, with a higher proportion of Caucasians, lower education level, lower BMI and fat mass, higher total energy intake, and lower leptin and CRP concentrations than the women in this survey (Table 1**)**. African-Americans had lower education and income levels, a higher percentage of current smokers, but lower alcohol consumption proportions, higher BMI and fat mass, and higher leptin and CRP concentrations; whereas their sICAM-1 concentrations and DASH scores were lower than Caucasians.

Dietary patterns

The following two dietary patterns were derived by factor analysis (Table 2), named by the interpretation of the data. 1) The Western dietary pattern was positively related to the consumption of bread, pizza, sweets, potatoes, fat and sauces, meats, snacks, beverage, pasta, coffee and tea, poultry, grains, dairy products, and alcohol food groups. 2) The prudent dietary pattern was identified by high positive loading for fruit, vegetables, fish and shellfish, cereal, legumes and soy, egg, and nuts.

Correlations among anthropometric and laboratory variables, and dietary indices and dietary pattern scores

The AHEI-2010 or DASH scores were negatively correlated with weight, BMI, fat mass, WC, and CRP ($r = -0.29$, $P < 0.001$ for AHEI-2010; $r = -0.33$, $P < 0.001$ for DASH), whereas the percent of fat-free mass was positively correlated (Table 3). Western diet scores were positively correlated with total energy intake ($r = 0.85$, $P < 0.001$). In contrast, the correlation between prudent dietary scores and other variables was similar to that of the AHEI-2010 or DASH scores and others, except for the case of sICAM-1, which was negatively correlated with prudent dietary scores ($r = -0.17$, $P = 0.030$).

Relationship between dietary indices, dietary patterns, and biomarkers

AHEI-2010 scores were negatively associated with leptin concentrations after adjusting for sociodemographic parameters (standardized $\beta = -0.22$, $P = 0.005$ in model 1) (Table 4). Moreover, AHEI-2010 and DASH scores were negatively associated with CRP concentrations after adjusting for demographic variables, health-related behaviors, BMI, and total energy intake (standardized $\beta = -0.21$, $P = 0.018$ for AHEI-2010; standardized $\beta = -0.20$, $P = 0.023$ for DASH in model 2). DASH scores were positively associated with irisin concentrations after controlling for all possible confounding factors (standardized $\beta = 0.23$, $P = 0.030$ in model 3). Leptin, sICAM-1, and CRP concentrations were positively associated with Western diet scores in model 2. These associations remained significant for leptin (standardized $\beta = 0.50$, $P = 0.008$) and sICAM-1 (standardized $\beta = 0.52$, $P = 0.013$), even after adjusting for mutual biomarkers, though CRP lost its significance. Prudent diet scores were negatively associated with leptin, sICAM-1, and CRP concentrations after controlling for sociodemographic variables. Leptin and sICAM-1 remained significant after adjusting for all confounders (standardized $\beta = -0.24$, $P = 0.009$ for leptin; standardized $\beta = -0.22$, $P = 0.034$ for sICAM-1 in model 3). Prudent scores were positively associated with irisin concentrations, after adjusting for all possible confounders (standardized $\beta = 0.25$, $P = 0.021$ in model 3).

Biomarker concentrations according to the tertile of food groups or items

The concentrations of leptin showed a decreasing trend when the consumption of fruit, vegetables, legumes and soy, fish, and eggs increased, after adjusting for sociodemographic variables, and there was a positive relationship between leptin concentrations and alcohol consumption after adjusting for all possible confounders (Table 5). Lower sICAM-1 concentrations were related to a higher intake of fish, whereas higher concentrations of sICAM-1 were associated with a higher consumption of dairy after adjusting for all confounders. Similarly, CRP concentrations decreased as the consumption of fruit, vegetables, wholegrain, fish, and nuts and seeds increased after controlling for sociodemographic variables, whereas the concentrations of CRP increased as the consumption of meats and alcohol increased after adjusting for all confounders. Irisin concentrations showed positive associations with increasing fruit consumption, whereas the levels of irisin decreased as the meat consumption increased, after controlling for all confounding factors.

Discussion

In this study, irisin was positively correlated with healthy diet type or pattern, assessed by DASH scores and prudent diet pattern, whereas other inflammatory biomarkers such as leptin, sICAM-1, and CRP were inversely correlated with healthy diet and directly associated with Western dietary scores. Higher fruit and lower meat consumption were related to higher levels of circulating irisin, which were different from the trends between other biomarkers and food groups.

Irisin is a novel myokine, which is dependent on peroxisome proliferator–activated receptor-γ coactivator 1-α (PGC-1α).[20] It is secreted from skeletal muscle after exercise, mediating glucose metabolism and exercise-related energy expenditure.[21] Irisin affects white adipose tissue by inducing browning to consume more energy via thermogenesis.[20] Although several studies have revealed that irisin is linked with the risk of metabolic syndrome, nonalcoholic fatty liver disease, and CVD,[6,22] there is only one report on the relationship between dietary quality and irisin, which fails to demonstrate the association.[11] We found that irisin was positively associated with the DASH and prudent diet scores. Irisin concentrations also showed an increasing trend as the consumption of fruit increased and that of meats decreased. This is the first report demonstrating an association between diet type/pattern and circulating irisin concentrations, but the underlying mechanism remains unknown.

Hyperleptinemia is associated with a high BMI, body fat, and apparently through these factors with metabolic syndrome, CVD, and dietary factors.[8] AHEI-2010 scores were negatively associated with leptin concentrations in this study, which may suggest that a healthy diet is related to the reduced concentrations of leptin, though the relationship was no more significant after controlling for BMI.

Among dietary factors, the Health Professionals Follow-up Study shows that the Western dietary pattern was related to high leptin concentrations, though the association lost its significance after controlling for BMI.[8] However, a recent Chinese study revealed that the positive relationship between the Western dietary pattern scores and leptin concentrations persisted even after adjusting for BMI,[10] which is in accordance with our results. Moreover, we found that the prudent diet pattern is negatively associated with circulating leptin concentrations after controlling for all possible confounders, which is also a novel finding. This may demonstrate that the beneficial effect of a prudent diet is not fully explained by BMI or total energy intake.

The intake of fruit, vegetables, legumes and soy, fish, and eggs was negatively correlated with leptin concentrations in this study, which is in accordance with previous evidence.[15,16] However, this association lost its significance after controlling for BMI and total energy. In contrast, alcohol consumption was positively correlated with leptin concentration, even after adjusting for all confounding variables. The relationship between alcohol consumption and leptin concentration is complex and inconclusive between studies,[13,14] which warrants future large-scale, well-designed investigation.

Adherence to a healthy diet seems to be associated with a low sICAM-1 concentration. High AHEI scores were related to a lower concentration of sICAM-1, with or without adjusting for BMI.[1] Consistent with our study, a pattern of wholegrain and fruit that is close to the prudent dietary pattern has been shown to be inversely related to sICAM-1 concentration.[23] Meanwhile, the Western diet pattern was associated with a high sICAM-1 concentration,[24] which is also in accordance with our results. This association remained significant, even after adjusting for BMI and other biomarkers.

In our analysis, a higher intake of fish was related with a low sICAM-1 concentration, while there was a positive association between dairy intake and sICAM-1 concentration, even after controlling for BMI, total energy, and other biomarkers. Fatty fish intake inhibited the concentration of sICAM-1 in a prior trial[25]; however, in yet another study, lean fish decreased the sICAM-1 concentration, while fatty fish or fish oil had no significant effect.[26] The association between dairy intake and sICAM-1 concentration was also inconsistent. A recent systemic review of dairy products and inflammatory biomarkers showed that some studies showed an improvement in several biomarkers except for sICAM-1, while others showed no effect.[12]

We found that serum CRP concentrations were negatively associated with diet quality, assessed using the AHEI-2010 and DASH scores, and the prudent diet scores, while the Western diet scores were positively associated with CRP. DASH diet and higher AHEI scores were associated with lower CRP concentrations[1,27]; however, the association between AHEI-2010 or DASH diet scores and CRP concentrations have not yet been studied. Several studies have demonstrated that people with high Western diet pattern scores have elevated CRP concentrations, whereas those with a high score for prudent diet patterns showed lower CRP concentrations.[8,24] In this study, the consumption of fruits, vegetables, wholegrain, fish, and nuts was negatively correlated with the concentrations of CRP, which is in accordance with previous reports.[23,28] In contrast, meat and alcohol intake was directly correlated with CRP, which is also in line with recent publications,[29,30] and this relationship remained significant after controlling for BMI, total energy, and other biomarkers.

The present study has several limitations. First, the process of choosing food items included in the principal component analysis was subjective and arbitrary. There also exists ambiguity in deciding the number of factors extracted and the naming of the components. However, the two extracted patterns in this study correspond with those published previously in the literature, and the food items in each pattern were well matched.[8,24] Second, there could be a recall bias or error when attempting to determine the amount of food consumed accurately. However, non-differential or random bias tends to suppress the effect of estimates towards null, and the FFQ that was used in this analysis was reliable and well-validated.[17] Finally, dietary patterns are different according to gender, race, socioeconomic class, geographic areas, and cultural groups, which makes it difficult to apply the results of this study to the general population.

In conclusion, irisin was directly associated with the DASH and the prudent diet scores after adjusting for all confounding factors. Higher irisin concentrations were associated with higher fruit and lower meat intakes. Further studies using large populations with other ethnic groups and closer examination of the mechanisms are warranted.

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Abbreviations

AHEI-2010	alternate healthy eating index-2010
BMI	body mass index
CVD	cardiovascular disease

CRP	C-reactive protein
DASH	dietary approaches to stop hypertension
FFQ	food frequency questionnaire
sICAM-1	soluble intracellular adhesion molecule 1
WC	waist circumference

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Table 1

General characteristics of participants at baseline

	Total (n = 196)	Gender			Race		
		Males (n = 96)	Females (n = 100)	P [a]	Caucasians (n = 92)	African-Americans (n = 103)	P [a]
Age, *y*	46.0 (43.0-48.0)	46.0 (44.0-49.0)	45.0 (43.0-48.0)	0.015	46.0 (44.0-48.0)	46.0 (43.0-48.0)	0.922
Gender, female, %	51.0				42.4	58.7	0.023
Race, white, %	46.9	55.2	39.0	0.023			
Education level, ≤14 years, %	57.4	70.0	44.2	0.001	42.0	70.5	<0.001
Income level, below 30,000 USD/y, %	56.4	57.1	55.7	0.852	44.7	66.7	0.005
Marriage, yes, %	31.8	28.4	35.1	0.324	42.4	22.0	0.002
Smoking status				0.987			0.009
Current smoker, %	33.5	34.0	33.0		28.1	38.4	
Ex-smoker, %	16.0	16.0	16.0		10.1	21.2	
Alcohol drinker, %	72.4	70.8	74.0	0.620	80.4	65.4	0.019
Regular physical Activity, %	76.9	80.9	73.1	0.213	78.8	75.3	0.569
Height, *cm*	171.3 (163.2-177.3)	176.9 (172.2-182.8)	164.7 (158.5-169.4)	<0.001	171.5 (165.3-177.6)	171.0 (162.3-176.7)	0.397
Weight, *kg*	86.2 (71.4-101.0)	88.9 (74.9-104.5)	83.2 (66.7-98.4)	0.026	80.6 (66.9-96.4)	88.6 (74.7-106.9)	0.005
BMI, kg/m^2	28.8 (25.1-33.7)	28.2 (24.4-32.2)	30.3 (25.4-36.4)	0.030	27.2 (23.5-32.3)	30.3 (26.3-36.7)	0.001
Fat mass, *%*	30.4 (22.8-38.7)	24.2 (16.4-28.9)	38.1 (33.1-43.1)	<0.001	28.6 (19.0-34.6)	32.0 (24.6-41.9)	0.001
Fat-free mass, *%*	69.6 (61.3-77.2)	75.8 (71.1-83.6)	62.0 (56.9-66.9)	<0.001	71.4 (65.4-81.0)	68.0 (58.2-75.5)	0.001
Fat mass, *kg*	25.3 (16.7-36.5)	21.0 (12.1-29.9)	31.7 (23.1-42.2)	<0.001	22.7 (13.5-32.8)	27.6 (20.1-40.2)	0.001
Fat-free mass, *kg*	58.3 (49.3-69.5)	68.6 (59.2-77.4)	49.7 (44.4-57.1)	<0.001	58.2 (47.9-71.5)	58.9 (49.9-69.1)	0.845
WC, *cm*	97.1 (87.4-111.5)	96.4 (86.0-111.5)	98.0 (88.3-110.8)	0.772	94.3 (86.5-111.2)	101.2 (87.7-114.0)	0.103
Total energy intake, *kJ/d*	7860.9 (5614.5-11019.4)	9023.6 (6169.7-13172.5)	7637.9 (5317.0-10555.8)	0.035	7525.8 (5494.4-10517.3)	8962.5 (5816.2-12406.4)	0.266
Leptin, *ng/mL*	20.5 (5.9-36.4)	10.3 (2.6-28.6)	24.5 (15.7-43.0)	<0.001	14.0 (3.7-28.5)	24.4 (13.1-42.7)	0.004
sICAM-1, *ng/mL*	183.6 (145.1-227.2)	185.9 (148.2-227.6)	180.6 (141.7-227.8)	0.197	191.6 (164.1-226.1)	172.4 (101.4-228.1)	<0.001
CRP, *mg/L*	1.3 (0.5-3.4)	0.9 (0.4-2.5)	1.8 (0.6-4.5)	0.004	0.9 (0.4-2.4)	1.9 (0.6-4.5)	0.008
Irisin, *ng/mL*	161.4 (113.7-210.8)	162.1 (105.9-211.0)	160.4 (118.9-211.0)	0.853	149.1 (93.6-203.0)	170.4 (125.3-230.3)	0.054
AHEI-2010	55.0 (44.8-63.1)	54.8 (43.8-62.2)	55.6 (46.9-65.0)	0.200	57.2 (46.9-64.4)	52.6 (43.0-62.2)	0.181
DASH	24.0 (20.0-28.0)	24.0 (20.0-28.0)	24.5 (20.0-28.0)	0.990	25.0 (22.0-29.0)	22.0 (19.0-26.0)	0.008

Data are presented as percentage or median (interquartile range). Variables which did not follow normal distribution were log-transformed before analysis. AHEI-2010, alternate healthy eating index-2010; CRP, C-reactive protein; DASH, dietary approaches to stop hypertension; sICAM-1, soluble intracellular adhesion molecule 1; WC, waist circumference.

[a]Gender, race, education level, income level, smoking status, alcohol drinking, and physical activity were assessed by chi-square test. Other continuous variables were assessed by *t* test.

Table 2

Factor loadings matrix for two dietary patterns

Foods or food group	Western diet (factor 1)	Prudent diet (factor 2)
Bread	0.82	
Pizza	0.77	
Sweets	0.76	
Potatoes	0.71	
Fat & sauces	0.65	
Meats	0.60	
Snacks	0.59	
Beverage	0.51	
Pasta	0.44	
Coffee & tea	0.44	
Poultry	0.42	
Grains	0.39	
Dairy products	0.36	
Alcohol	0.31	
Fruit		0.79
Vegetables		0.64
Fish & shellfish		0.63
Cereal		0.59
Legumes & soy		0.46
Eggs		0.41
Nuts		0.37

Factor loading values less than 0.30 are not listed in the matrix for simplicity. Two dietary patterns were derived by principal component analysis after entering the 21 food groups into the FACTOR PROCEDURE. The factors were rotated by orthogonal transformations (Varimax rotation function in SAS).

Table 3

Spearman correlation coefficients (*r*) among anthropometric and laboratory variables, dietary indices, and dietary pattern scores

	AHEI-2010		DASH		Western diet (factor 1)		Prudent diet (factor 2)	
	r	***P***	***r***	***P***	***r***	***P***	***r***	***P***
Height, *cm*	−0.04	0.580	0.00	0.959	0.14	0.055	0.02	0.839
Weight, *kg*	−0.23	0.002	−0.23	0.001	0.08	0.293	−0.18	0.013
BMI, kg/m^2	−0.24	0.001	−0.26	<0.001	0.04	0.615	−0.21	0.003
Fat mass, *%*	−0.17	0.023	−0.22	0.003	−0.05	0.526	−0.17	0.027
Fat-free mass, *%*	0.17	0.023	0.22	0.003	0.05	0.526	0.17	0.026
Fat mass, *kg*	−0.23	0.002	−0.26	<0.001	0.02	0.792	−0.21	0.005
Fat-free mass, *kg*	−0.13	0.071	−0.08	0.289	0.14	0.068	−0.07	0.353
WC, *cm*	−0.27	<0.001	−0.28	<0.001	0.11	0.144	−0.26	<0.001
Total energy intake, *kJ/d*	0.33	<0.001	−0.09	0.212	0.85	<0.001	0.32	<0.001
Leptin, *ng/mL*	−0.12	0.100	−0.13	0.071	0.00	0.958	−0.11	0.136
sICAM-1, *ng/mL*	−0.11	0.163	−0.07	0.346	0.09	0.243	−0.17	0.030
CRP, *mg/L*	−0.29	<0.001	−0.33	<0.001	0.04	0.586	−0.21	0.008
Irisin, *ng/mL*	−0.01	0.883	0.04	0.553	−0.05	0.508	0.01	0.863

AHEI-2010, alternate healthy eating index-2010; CRP, C-reactive protein; DASH, dietary approaches to stop hypertension; sICAM-1, soluble intracellular adhesion molecule 1; WC, waist circumference.

Table 4

β regression coefficients for the relationships between log-transformed biomarkers and dietary indices and dietary pattern scores

Dietary pattern or index	Log-Leptin, *ng/mL*		Log-sICAM-1, *ng/mL*		Log-CRP, *mg/L*		Log-Irisin, *ng/mL*	
	Standardized β	*P*	Standardized β	*P*	Standardized β	*P*	Standardized β	*P*
AHEI-2010								
Model 1	−0.22	0.005	−0.15	0.078	−0.31	<0.001	0.01	0.890
Model 2	−0.13	0.132	−0.12	0.266	−0.21	0.018	0.12	0.224
Model 3	−0.08	0.416	−0.11	0.294	−0.16	0.103	0.21	0.056
DASH								
Model 1	−0.16	0.055	−0.10	0.247	−0.31	0.001	0.14	0.113
Model 2	−0.04	0.610	−0.07	0.509	−0.20	0.023	0.21	0.025
Model 3	−0.07	0.434	−0.07	0.534	−0.16	0.095	0.23	0.030
Western diet (factor 1)								
Model 1	0.06	0.437	0.03	0.760	0.03	0.734	−0.08	0.367
Model 2	0.42	0.006	0.44	0.024	0.41	0.021	−0.05	0.781
Model 3	0.50	0.008	0.52	0.013	0.25	0.200	−0.31	0.164
Prudent diet (factor 2)								
Model 1	−0.26	0.001	−0.19	0.029	−0.24	0.005	0.03	0.707
Model 2	−0.19	0.019	−0.18	0.073	−0.15	0.098	0.13	0.191
Model 3	−0.24	0.009	−0.22	0.034	−0.09	0.332	0.25	0.021

Model 1 was adjusted for age, gender, race, education, income, and marriage. Model 2 was adjusted for all covariates in model 1 plus smoking status, alcohol intake, physical activity, BMI, and total energy. Model 3 was adjusted for all covariates in model 2 plus mutual biomarkers (leptin, sICAM-1, CRP, and irisin). AHEI-2010, alternate healthy eating index-2010; CRP, C-reactive protein; DASH, dietary approaches to stop hypertension; sICAM-1, soluble intracellular adhesion molecule 1.

Table 5

Leptin, sICAM-1, CRP, and irisin concentrations by tertile of selected food group consumption

		T1	T2	T3	*P*-trend[a]	*P*-trend[b]	*P*-trend[c]
Fruit	Range, *cups/d*	0.05-0.65	0.65-1.27	1.29-5.00			
	Leptin, *ng/mL*	18.1 ± 1.2	12.8 ± 1.2	11.8 ± 1.2	0.045	0.629	0.341
	sICAM-1, *ng/mL*	189.4 ± 1.1	162.8 ± 1.1	157.7 ± 1.1	0.073	0.222	0.211
	CRP, *mg/L*	1.9 ± 1.2[a]	1.1 ± 1.2	1.0 ± 1.2[b]	0.004	0.214	0.516
	Irisin, *ng/mL*	141.9 ± 1.1[a]	192.9 ± 1.1[b]	187.2 ± 1.1[b]	0.334	0.031	0.009
Vegetables	Range, *cups/d*	0.03-0.85	0.86-1.63	1.64-5.80			
	Leptin, *ng/mL*	20.7 ± 1.2[a]	12.5 ± 1.2	11.4 ± 1.2[b]	0.009	0.148	0.126
	sICAM-1, *ng/mL*	172.4 ± 1.1	169.6 ± 1.1	168.3 ± 1.1	0.832	0.504	0.565
	CRP, *mg/L*	1.8 ± 1.2	1.3 ± 1.2	1.0 ± 1.2	0.020	0.451	0.487
	Irisin, *ng/mL*	155.7 ± 1.1	144.8 ± 1.1	151.1 ± 1.1	0.776	0.612	0.289
Legumes and soy	Range, *cups/d*	0.00-0.04	0.04-0.12	0.12-2.96			
	Leptin, *ng/mL*	18.6 ± 1.2[a]	15.0 ± 1.2	10.6 ± 1.2[b]	0.012	0.146	0.258
	sICAM-1, *ng/mL*	171.6 ± 1.1	173.8 ± 1.1	165.2 ± 1.1	0.717	0.649	0.718
	CRP, *mg/L*	1.4 ± 1.2	1.7 ± 1.2[a]	0.9 ± 1.2[b]	0.054	0.517	0.917
	Irisin, *ng/mL*	144.1 ± 1.1	155.3 ± 1.1	150.1 ± 1.1	0.698	0.223	0.199
Grain	Range, *g/d*	9.78-114.82	116.80-189.94	194.19-1066.79			
	Leptin, *ng/mL*	16.5 ± 1.2	13.9 ± 1.2	11.9 ± 1.2	0.142	0.118	0.179
	sICAM-1, *ng/mL*	170.1 ± 1.1	170.4 ± 1.1	169.5 ± 1.1	0.975	0.391	0.269
	CRP, *mg/L*	1.6 ± 1.2	1.1 ± 1.2	1.1 ± 1.2	0.149	0.514	0.512
	Irisin, *ng/mL*	162.1 ± 1.1	156.9 ± 1.1	132.6 ± 1.1	0.051	0.108	0.351
Whole grain	Range, *g/d*	0.26-19.36	19.70-39.97	40.54-166.98			
	Leptin, *ng/mL*	18.2 ± 1.2	11.4 ± 1.2	13.4 ± 1.2	0.183	0.989	0.504
	sICAM-1, *ng/mL*	181.2 ± 1.1	156.2 ± 1.1	173.6 ± 1.1	0.730	0.790	0.630
	CRP, *mg/L*	1.9 ± 1.2[a]	1.2 ± 1.2	1.0 ± 1.2[b]	0.013	0.232	0.198
	Irisin, *ng/mL*	156.3 ± 1.1	142.5 ± 1.1	151.7 ± 1.1	0.794	0.508	0.759
Fish	Range, *g/d*	0.23-10.92	11.23-27.50	27.53-371.10			
	Leptin, *ng/mL*	16.3 ± 1.2	16.5 ± 1.2	10.1 ± 1.2	0.037	0.458	0.943
	sICAM-1, *ng/mL*	205.4 ± 1.1	170.9 ± 1.1	155.8 ± 1.1	0.032	0.058	0.028
	CRP, *mg/L*	1.8 ± 1.2	1.1 ± 1.2	1.0 ± 1.2	0.033	0.445	0.664
	Irisin, *ng/mL*	159.3 ± 1.1	149.2 ± 1.1	141.6 ± 1.1	0.258	0.528	0.716
Meats (beef, pork, and lamb)	Range, *g/d*	0.43-20.19	20.24-51.60	53.52-310.43			
	Leptin, *ng/mL*	13.6 ± 1.2	14.1 ± 1.2	14.5 ± 1.2	0.761	0.471	0.370
	sICAM-1, *ng/mL*	169.8 ± 1.1	164.5 ± 1.1	178.9 ± 1.1	0.689	0.328	0.451
	CRP, *mg/L*	1.0 ± 1.2	1.3 ± 1.2	1.9 ± 1.3	0.175	0.010	0.015
	Irisin, *ng/mL*	205.8 ± 1.1[a]	161.8 ± 1.1[b]	148.6 ± 1.1[b]	0.002	0.001	0.008
Nuts, seeds	Range, *g/d*	0.09-5.53	5.67-19.22	19.25-139.76			

		T1	T2	T3	*P*-trend[a]	*P*-trend[b]	*P*-trend[c]
	Leptin, *ng/mL*	17.4 ± 1.2	11.6 ± 1.2	13.8 ± 1.2	0.295	0.771	0.487
	sICAM-1, *ng/mL*	180.8 ± 1.1	160.2 ± 1.1	169.5 ± 1.1	0.569	0.785	0.759
	CRP, *mg/L*	1.9 ± 1.2	1.1 ± 1.2	1.1 ± 1.2	0.036	0.275	0.413
	Irisin, *ng/mL*	140.0 ± 1.1	153.3 ± 1.1	157.4 ± 1.1	0.258	0.052	0.149
Eggs	Range, *g/d*	0.17-5.61	5.76-14.80	16.33-110.00			
	Leptin, *ng/mL*	18.0 ± 1.2	14.0 ± 1.2	11.0 ± 1.2	0.029	0.157	0.302
	sICAM-1, *ng/mL*	184.7 ± 1.1	161.4 ± 1.1	166.3 ± 1.1	0.310	0.392	0.309
	CRP, *mg/L*	1.3 ± 1.2	1.2 ± 1.2	1.4 ± 1.2	0.964	0.283	0.257
	Irisin, *ng/mL*	155.3 ± 1.1	147.8 ± 1.1	147.6 ± 1.1	0.620	0.993	0.571
Dairy	Range, *cups/d*	0.06-0.71	0.72-1.37	1.40-5.31			
	Leptin, *ng/mL*	17.0 ± 1.2	10.9 ± 1.2	15.1 ± 1.2	0.574	0.225	0.893
	sICAM-1, *ng/mL*	155.4 ± 1.1	178.4 ± 1.1	211.1 ± 1.1	0.491	0.042	0.036
	CRP, *mg/L*	1.5 ± 1.2	1.0 ± 1.2	1.4 ± 1.2	0.636	0.050	0.075
	Irisin, *ng/mL*	162.4 ± 1.1	149.6 ± 1.1	138.0 ± 1.1	0.111	0.311	0.247
Alcohol[d]	Range, equiv. about 13 *g EtOH/d*	0.00-0.00	0.00-0.47	0.47-22.46			
	Leptin, *ng/mL*	10.8 ± 1.2	14.2 ± 1.2	18.0 ± 1.2	0.769	0.189	0.024
	sICAM-1, *ng/mL*	178.2 ± 1.1	170.3 ± 1.1	163.6 ± 1.1	0.418	0.603	0.485
	CRP, *mg/L*	1.0 ± 1.2	1.2 ± 1.2	1.6 ± 1.2	0.975	0.077	0.048
	Irisin, *ng/mL*	152.6 ± 1.1	149.5 ± 1.1	148.6 ± 1.1	0.794	0.930	0.761

Data are presented as geometric means ± SEs adjusted for covariates in model 1. Leptin values in alcohol consumption, sICAM-1 in fish and dairy, CRP in meats and alcohol, and irisin in fruit and meats were adjusted for covariates in model 3. Means in a row with superscript without a common letter differ, $P < 0.05$ in *a post-hoc* analysis (Bonferroni). Model 1 was adjusted for age, gender, race, education, income, and marriage. Model 2 was adjusted for all covariates in model 1 plus smoking status, alcohol intake, physical activity, BMI, and total energy. Model 3 was adjusted for all covariates in model 2 plus mutual biomarkers (leptin, sICAM-1, CRP, and irisin). CRP, C-reactive protein; sICAM-1, soluble intracellular adhesion molecule 1.

[a] *P*-tvend in model 1.

[b] *P*-trend in model 2.

[c] *P*-tvend in model 3.

[d] Alcohol intake was not included as a covariate in model 2 and 3.