Validation of the Healthy Eating Index with use of plasma biomarkers in a clinical sample of women[1–3]

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ABSTRACT

Background: The Healthy Eating Index (HEI) is a 100-point analytic scoring tool used to measure compliance with dietary recommendations and guidelines.

Objective: The objective was to calculate HEI scores for a sample of women and to link the HEI scores to plasma biomarkers of dietary exposure.

Design: Respondents were 340 women aged 21–80 y who were enrolled in a case-control study of diet and breast cancer. The sample included 172 patients with newly diagnosed cancer (case subjects), 149 cancer-free control subjects, and 19 women at high risk of breast cancer. Dietary intake assessment was based on 3-d food records. HEI scores were calculated for all respondents. Venous blood was collected for measurements of plasma carotenoids, vitamin C, and folate.

Results: Higher HEI scores were associated most strongly with greater dietary variety ($r = 0.71$), higher intakes of fruit ($r = 0.57$), and lower intakes of fat and saturated fat. HEI scores were also associated with higher intakes of energy, carbohydrates, fiber, folate, and vitamin C. Higher HEI scores were associated with higher plasma concentrations of α-carotene ($r = 0.40$), β-carotene ($r = 0.28$), β-cryptoxanthin ($r = 0.41$), lutein ($r = 0.23$), and vitamin C ($r = 0.26$) after age and vitamin supplement use were controlled for in a regression model. There was a further association between HEI scores and socioeconomic variables. Women with higher HEI scores were more likely to be older, married, and better educated and to have higher household incomes.

Conclusions: The HEI is a useful tool for describing the overall diet pattern and represents a promising new tool for nutritional epidemiology. Diet quality, as defined by the HEI, varies with age and socioeconomic status. *Am J Clin Nutr* 2001;74: 479–86.

KEY WORDS Diet, nutrition, diet quality, Healthy Eating Index, food guide pyramid, dietary guidelines, cancer, women, socioeconomic status, plasma biomarkers, carotenoids, vitamin C

INTRODUCTION

Epidemiologic studies of diet and chronic disease have tended to focus on the relation between single-nutrient consumption and disease risk. The traditional approach has been to link the consumption of fats (1), saturated fat (2), protein (3), or alcohol (4) to the risk of coronary heart disease or cancer. However, most foods contain many nutrients, such that intakes of one nutrient are often correlated with intakes of another (5). The single-nutrient approach does not allow for an examination of nutrient interactions and their combined effect on health outcomes.

Some investigators have shifted their attention to the relation between the consumption of individual foods and disease risk. The consumption of nuts (6), eggs (7), salad dressings (8), and Brussels sprouts (9) was examined in relation to the risk of cancer or coronary heart disease. However, diets are composed of many different foods. The single-food, like the single-nutrient, approach does not account for the complexity of eating habits and does not reflect the multifaceted nature of the human diet. Nutrient bioavailability and absorption often depend on food preparation methods and eating patterns (10–13). Most recently, studies have begun to explore the connection between diet structure (10, 12) and selected health outcomes. For example, Hu et al (12) used factor analyses of food-frequency data to distinguish between healthy and Western diet structures.

In an effort to measure how well American diets conform to the recommended healthy eating patterns, the US Department of Agriculture (USDA) developed a measure of overall diet quality—the Healthy Eating Index (HEI; 14). The HEI is a 100-point analytic tool designed to measure the degree to which a person's diet conforms to such dietary guidelines as the USDA/US Department of Health and Human Services *Food Guide Pyramid* (15) and the *Dietary Guidelines for Americans* (16). HEI scores, which are based on dietary balance, moderation, and variety (17), were calculated for respondents in the 1989–1990 Continuing Survey of Food Intake by Individuals (CSFII) (14). An interactive version of the HEI is now available online (18). The HEI was intended as a basis for nutrition promotion activities

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and as the principal tool for monitoring changes in the diet quality of consumers over time (14).

The field of diet quality assessment is not free of controversy. A key question is whether the existing dietary guidelines do, in fact, describe an optimal diet (19). Some researchers have failed to find an association between HEI scores, based on food-frequency questionnaires, and the risk of major chronic disease in women (19). Their conclusion is that adherence to dietary guidelines is of limited benefit in disease prevention (19). Others have questioned the benefits of dietary variety, suggesting that more varied diets were responsible for higher obesity rates (20). Dietary variety is 1 of the 10 components of the HEI (14, 16).

Another key issue is the impact of sociodemographic variables on diet quality. Analyses of CSFII data showed that women had higher HEI scores than did men and that scores improved with increasing education and income levels (17). Although no single factor accounts for the relation between income and health, socioeconomic disparities are increasingly viewed as a key determinant of disparities in health (21). Whereas some studies addressed the issue of diet quality in relation to income levels, most focused on the lower end of the income distribution (22). Such comparisons imply a great homogeneity among people above the threshold of poverty. It is important to know whether the relation between socioeconomic status and diet quality also holds for middle-income respondents.

Only limited data are available on the diet quality of clinic patients, and questions remain. Do HEI scores adequately reflect the consumption of vegetables and fruit, a common strategy for cancer prevention and control (23)? Are HEI scores correlated with plasma concentrations of carotenoids, folate, or vitamin C? Plasma carotenoids are biomarkers of long-term vegetable consumption in women with breast cancer (24). In the present study, we calculated HEI scores for a clinical sample of women recruited from a breast care clinic.

SUBJECTS AND METHODS

Respondents

Respondents were 340 women who were recruited from the University of Michigan Hospitals' Breast Care Center (BCC). The sample was drawn from consecutive admissions to the BCC for purposes of examination, diagnosis, or treatment of breast cancer. Women who were <18 y of age, who were pregnant or lactating, who had mental disabilities or language barriers that resulted in communication and comprehension problems, or who had other diseases that affected taste or smell were not eligible for the study. Women with a recurrence of previously diagnosed breast cancer or who were already receiving radiation or chemotherapy for breast cancer or another cancer were ineligible for the study. Women enrolled in the longitudinal cohort phase of the study were tested either before or shortly after diagnosis and before commencing any treatment. The present baseline sample included 172 women with newly diagnosed breast cancer (case subjects), 149 women with no cancer (control subjects), and 19 women at high risk of breast cancer. High-risk women had breast disorders such as atypical hyperplasia or had a past history of other cancers. The diagnoses were confirmed by a review of medical records. Weights and heights were measured and body mass indexes (BMIs; in kg/m^2) were calculated. The women also completed health and demographic questionnaires. The research protocols were approved by the Institutional Review Board of the University of Michigan. The women were compensated after completing 3 study sessions.

Dietary intake assessment

All women were instructed by a registered dietitian on how to keep food records. Dietary records for 3 d of intake, including at least one weekend day, were reviewed and discussed with the women, if necessary, to resolve any issues of inaccuracy or incompleteness. Data were coded, entered, and analyzed by using the NUTRITIONIST IV program (version 4.1, 1997; First DataBank, The Hearst Corporation, San Bruno, CA). The program contains data on >12 000 foods and food mixtures gathered from a wide variety of sources such as the USDA database and food manufacturers. The conversion of the data into food pyramid servings was accomplished by using the food servings database file from the 1994–1996 CSFII (25). This database contains food servings data on >8900 foods and contains standard servings of food mixtures partitioned into their constituent foods. The NUTRITIONIST IV food codes were converted to CSFII codes for the purpose of calculating pyramid servings by using a custom-made linking file, created by matching each of the 3424 unique NUTRITIONIST IV food codes with its CSFII equivalent. The final data set contained macronutrient intakes estimated by the NUTRITIONIST IV program and pyramid servings for food categories, as calculated from the CSFII database.

Blood chemistry measures

Fasting venous blood samples were obtained from the women at the time of enrollment. Plasma was separated by centrifugation at 2300 × *g* for 10 min at 4°C. Plasma samples were stored at −70°C until lipid extraction and analysis. One milliliter of plasma was separately collected, processed by using 10% trichloroacetic acid, and stored until analyzed for vitamin C. Plasma carotenoids were separated and quantified by using HPLC according to the method of Bieri et al (26), as modified by Craft et al (27, 28), with further modifications to reduce oxidative loss and improve recovery of compounds. Carotenoids were measured by reversed-phase HPLC with a mobile phase of acetonitrile:methanol:methylene chloride (70:10:20, by vol) and a detection setting of 450 nm. Plasma vitamin C was measured with the derivative spectrophotometric method of Omaye et al (29). Plasma folate was measured with a Quantaphase II radioassay kit according to the manufacturer's instruction manual (Bio-Rad Laboratories Inc, Hercules, CA). Plasma cholesterol and carotenoid concentrations were measured in 333 of the 340 respondents. Vitamin C concentrations were measured in 175 respondents, and folate concentrations were measured in 99 respondents.

The HEI

Each of the 10 components of the HEI was given a maximum score of 10 points (14). As shown in **Table 1**, the first 5 components of the HEI were based on compliance with the USDA *Food Guide Pyramid* recommendations for grains, vegetables, fruit, milk, and meat groups, as expressed in servings/d (15). Intakes at or above recommended amounts were awarded the full score of 10 points, whereas intermediate numbers of servings were awarded prorated scores. The next 4 components of the HEI were nutrient based and were adapted from the *Dietary Guidelines for Americans* (16). A full score of 10 points each was awarded for

TABLE 1
Components of the Healthy Eating Index[1]

Component	Scoring range	Criteria for maximum score of 10	Criteria for minimum score of 0
Grain consumption	0–10	9[2,3] or 7.4[4] servings	0 servings
Vegetable consumption	0–10	4[2,3] or 3.5[4] servings	0 servings
Fruit consumption	0–10	3[2,3] or 2.5[4] servings	0 servings
Milk consumption	0–10	3[2] or 2[3,4] servings	0 servings
Meat consumption	0–10	2.4[2,3] or 2.2[4] servings	0 servings
Total fat intake	0–10	≤30% of energy from fat	≥45% of energy from fat
Saturated fat intake	0–10	<10% of energy from saturated fat	≥15% of energy from saturated fat
Cholesterol intake	0–10	≤300 mg	≥450 mg
Sodium intake	0–10	≤2400 mg	≥4800 mg
Dietary variety	0–10	≥24 different items over 3 d	≤9 different items over 3 d

[1] Intakes between the maximum and minimum cutoffs were assigned scores proportionally.
[2] For women aged 20–24 y.
[3] For women aged 25–50 y.
[4] For women aged ≥51 y.

diets with <30% of energy from fat, <10% of energy from saturated fat, <300 mg cholesterol, and <2400 mg Na.

To assess dietary variety, the HEI score was calculated by counting the total number of different foods and food groups consumed over 3 d (14). Foods that were similar, such as 2 forms of white bread, were counted only once in the variety category. Mixtures were broken down into their component parts so that a single item could contribute ≥2 points to the variety index. For example, lasagna would contribute to the grain and meat groups. A threshold criterion ensured that foods were counted only if they contributed at least one-half of a serving in any of the food groups. HEI scores were calculated by using procedures developed by the USDA; tools and programs were supplied by Peter Basiotis of the Center for Nutrition Policy and Promotion (30). The only modification to the USDA procedure was that a respondent was allocated a variety score of 10 if ≥24, rather than 16 foods, were consumed over 3 d.

A method previously developed by the USDA was used to determine portion sizes and to allocate mixtures to individual food groups. Serving sizes for items in the 5 food groups (ie, HEI components 1–5) were based on the serving amounts specified in the *Food Guide Pyramid*. The program to convert foods from gram amounts to servings for each particular food group was supplied by the USDA's Center for Nutrition Policy and Promotion.

Statistical analyses

The SPSS statistical program (version 8.0; SPSS Inc, Chicago) was used for the data analyses. HEI scores were split into 4 groups on the basis of quartile analyses. Total scores ranged from a "poor" diet (HEI score < 65) to a "good" diet (HEI score ≥ 85), with scores of 65–74 and 75–84 in between. As in the past (14, 17), the HEI scores for each component were defined as poor (score < 5), needs improvement (score between 5 and 8), and good (score > 8). Analyses of trend by HEI category were based on an analysis of variance for trend. Correlations between variables were calculated by using Pearson product-moment correlations. Plasma carotenoid concentrations were corrected for lipid concentrations by dividing by plasma cholesterol concentrations (31, 32). Biomarker concentrations were log-transformed to improve normality (31–33). Because vitamin supplement use is an important confounding variable that affects the relation between HEI scores and circulating plasma biomarkers, a stepwise regression model in which vitamin supplement use and other possible confounding factors (eg, age, BMI, and energy intake) were controlled for was used to examine the relation between HEI scores and each of the circulating plasma biomarkers. Stepwise regression, based on the likelihood ratio test, was used to determine which variables were included or removed from the model. Independent variables entered in the regression were age, case or control status, energy intake, and vitamin supplement use.

RESULTS

Respondents

Respondent characteristics are shown in **Table 2**. The women were mostly white (91%), married (74%), and educated (>75% had "some college"), and 70% had household incomes in excess of the national median. Ethnicity, education level, and income level were not significantly different between case and control subjects. Case subjects were more likely to use vitamin supplements than were control subjects. The subjects' mean (±SEM) age was 49.9 ± 0.6 y (range: 21–80 y), their mean weight was 70.1 ± 0.8 kg, and their mean BMI was 26.1 ± 0.3 (**Table 3**). Case subjects were significantly older than control subjects, but no significant differences in height, weight, or BMI were observed.

Dietary intakes

Energy and nutrient intakes are shown in Table 3. There were no significant differences in energy, protein, carbohydrate, fat, fiber, or vitamin C intakes between case and control subjects. Therefore, data for all groups were pooled.

The HEI

The distribution of HEI scores for each of the 10 HEI components is shown in **Table 4**. For 6 of the 10 HEI components, the mean score was >8. The highest mean scores were obtained for cholesterol intake (9.3) and meat consumption (8.9), reflecting high compliance with these 2 dietary guidelines. In contrast, the scores for dietary variety and milk consumption were much lower (5.9 for both). Although 90.0% of the respondents obtained a good score for cholesterol intake, only 24.1% obtained a good score for dietary variety. The total HEI score was 77.3 points out

TABLE 2
Respondent characteristics[1]

Respondent characteristics	Case subjects (n = 172)	Control subjects (n = 149)
	n (%)	
Age (y)		
20–39	18 (10.5)	35 (23.5)
40–49	57 (33.1)	48 (32.2)
50–59	58 (33.7)	40 (26.8)
≥60	39 (22.7)	26 (17.4)
Ethnicity		
White	163 (94.8)	129 (86.6)
Nonwhite	9 (5.2)	20 (13.4)
Education level		
1–4 y of high school	39 (23.5)	23 (16.2)
Some college	56 (33.7)	45 (31.7)
College graduate	24 (14.5)	24 (16.9)
Postgraduate	47 (28.3)	49 (34.5)
Household income ($)		
0–24 999	21 (13.2)	21 (15.4)
25 000–39 999	31 (19.5)	19 (14.0)
40 000–69 999	46 (28.9)	37 (27.2)
≥70 000	61 (38.4)	59 (43.4)
Marital status		
Married	123 (73.7)	109 (74.7)
Divorced, widowed, or separated	34 (20.4)	24 (16.4)
Never married	10 (6.0)	13 (8.9)
Vitamin supplement use[2]		
Yes	127 (76.0)	88 (60.3)
No	40 (24.0)	58 (39.7)

[1] Values may not equal total number of subjects in each group because of missing data.
[2] Significant difference between case and control subjects, $P < 0.05$ (Student's t test and chi-square test).

of a possible 100. Only 1.8% of the women were deemed to have a poor diet. Almost 50% of the women (49.4%) were classified as having diets in need of improvement, whereas 48.8% were classified as having a good diet.

Dietary intakes by HEI score

As shown in **Table 5**, some foods and nutrients were used to calculate the HEI score and some were not. As expected, higher HEI scores were associated with an increased number of servings of grains, vegetables, and fruit. Servings of fruit and vegetables, respectively, increased from 0.7 and 3.0 for those with a poor diet to 4.5 and 4.9 for those with a good diet. The percentage of energy from fat and saturated fat and intakes of cholesterol and sodium decreased in going from a poor to a good diet, as expected. Other than for sodium, all correlations between the total HEI score and its 10 components were significant.

HEI scores were most strongly correlated with dietary variety (r = 0.71). The number of different foods eaten over 3 d almost doubled (from 12.4 foods to 22.2 foods) in going from a poor diet to a good diet. Another strong association was between HEI scores and fruit consumption (r = 0.57). HEI scores were moderately correlated (r = 0.21) with total energy intakes. Higher HEI scores were also associated with higher carbohydrate intakes (as a percentage of energy) and with higher intakes of fiber, folate, and vitamin C. Fiber, folate, and vitamin C intakes are common indicators of grain, vegetable, and fruit intakes.

HEI categories and biomarkers of dietary exposure

The relation between HEI categories and plasma concentrations of carotenoids, folate, and vitamin C is shown in **Table 6**. Carotenoid concentrations were corrected for serum cholesterol concentrations and all biomarker concentrations were log-transformed (31, 32). Higher HEI scores were associated with higher plasma concentrations of all carotenoids, except lycopene. Plasma α-carotene concentrations nearly tripled in going from a poor to a good diet. Plasma concentrations of β-carotene and β-cryptoxanthin increased by 73% (from 0.49 to 0.85 μmol/L) and by 127% (from 0.11 to 0.25 μmol/L), respectively, in going from a poor to a good diet. Higher HEI scores were significantly associated with higher concentrations of both β-carotene and β-cryptoxanthin. HEI scores were also correlated with lutein, vitamin C, and folate concentrations. There were no significant correlations between HEI scores and plasma cholesterol concentrations.

TABLE 3
Respondent characteristics and dietary intakes[1]

Characteristic	Case subjects (n = 172)	Control subjects (n = 149)	Total[2] (n = 340)
Age (y)	51.8 ± 0.8	47.7 ± 1.0[3]	49.9 ± 0.6
Height (cm)	164.3 ± 0.5	164.4 ± 0.5	164.1 ± 0.4
Weight (kg)	69.3 ± 1.0	71.4 ± 1.3	70.1 ± 0.8
BMI (kg/m^2)	25.7 ± 0.4	26.5 ± 0.5	26.1 ± 0.3
Dietary intakes			
Energy			
(kJ/d)	7091 ± 138	7284 ± 184	7217 ± 109
(kcal/d)	1694 ± 33	1740 ± 44	1724 ± 26
Fat (% of energy)	28.9 ± 0.6	29.2 ± 0.6	29.2 ± 0.4
Carbohydrate (% of energy)	55.7 ± 0.7	55.0 ± 0.8	55.4 ± 0.5
Protein (% of energy)	16.1 ± 0.3	16.5 ± 0.3	16.3 ± 0.2
Fiber (g/d)	17 ± 1	16 ± 1	17 ± 1
Vitamin C (mg/d)	127 ± 6	118 ± 7	125 ± 4
Total vegetables (servings/d)	4.4 ± 0.2	4.1 ± 0.2	4.3 ± 0.1
Total fruit (servings/d)	3.1 ± 0.2	2.8 ± 0.2	3.0 ± 0.1

[1] $\bar{x}$ ± SEM.
[2] Includes 172 case subjects, 149 control subjects, and 19 patients at high risk of breast cancer.
[3] Significantly different from case subjects, $P < 0.01$.

TABLE 4
Distribution of Healthy Eating Index scores for each of the 10 components

Component	Mean score	Percentage obtaining score: Poor (score <5)	Needs improvement (score 5–8)	Good (score >8)
			%	
Grain consumption	7.2	18.5	40.9	40.6
Vegetable consumption	8.4	10.0	24.1	65.9
Fruit consumption	7.2	27.1	17.1	55.9
Milk consumption	5.9	42.4	27.1	30.6
Meat consumption[1]	8.9	6.5	17.1	76.5
Total fat intake	8.3	12.6	18.8	68.5
Saturated fat intake	8.1	17.1	12.1	70.9
Cholesterol intake	9.3	5.6	4.4	90.0
Sodium intake	8.0	13.8	22.9	63.2
Dietary variety	5.9	37.4	38.5	24.1
Total[2]	77.3	1.8	49.4	48.8

[1] Includes eggs, nuts, and legumes.
[2] To obtain value, criterion was multiplied by 10 (ie, for good score, score >80).

Regression model

Regression coefficients for the effects of HEI scores on each plasma biomarker, adjusted for age and vitamin supplement use, are shown in **Table 7**. As expected, higher HEI scores were associated with higher concentrations of α-carotene, β-carotene, β-cryptoxanthin, and lutein. These coefficients were all significant. The relation between HEI scores and plasma vitamin C (standardized β coefficient = 0.26) may have been weakened because plasma vitamin C data were available for only 175 of 340 respondents.

HEI scores and socioeconomic status

As shown in **Table 8**, HEI scores were significantly influenced by age, education level, and income level. Higher HEI scores were obtained for those women who were older, better educated, and more affluent, and higher HEI scores were obtained for women who were married as opposed to widowed or divorced. Ethnicity had no effect on HEI scores in this sample, although the number of nonwhite women was small. Women who took vitamin supplements were also more likely to have higher HEI scores.

TABLE 5
Differences in food and nutrient intakes by Healthy Eating Index (HEI) score category

Variable	HEI score category: Poor diet <65 (*n* = 58)	65–74 (*n* = 65)	75–84 (*n* = 110)	Good diet ≥85 (*n* = 107)	*P* for trend	Correlation with HEI (*r*)
Within HEI model						
Grains (servings/d)	5.4 ± 0.3[1]	5.5 ± 0.2	6.6 ± 0.2	6.8 ± 0.2	<0.001	0.27[2]
Vegetables (servings/d)	3.0 ± 0.2	3.6 ± 0.4	4.2 ± 0.2	4.9 ± 0.2	<0.001	0.29[2]
Fruit (servings/d)	0.7 ± 0.1	2.2 ± 0.2	3.3 ± 0.2	4.5 ± 0.2	<0.001	0.57[2]
Milk (servings/d)	1.2 ± 0.2	1.2 ± 0.1	1.2 ± 0.1	1.7 ± 0.1	<0.001	0.21[2]
Meat (servings/d)	2.0 ± 0.6	2.0 ± 0.6	2.1 ± 0.4	2.1 ± 0.4	NS	0.16[2]
Fat (% of energy)	36.9 ± 0.6	32.8 ± 1.1	27.8 ± 0.6	24.4 ± 0.6	<0.001	−0.58[2]
Saturated fat (% of energy)	12.6 ± 0.3	10.7 ± 0.4	8.8 ± 0.3	7.4 ± 0.2	<0.001	−0.56[2]
Cholesterol (mg/d)	238 ± 20	203 ± 13	191 ± 9	161 ± 7	<0.001	−0.22[2]
Sodium (mg/d)	2771 ± 172	2464 ± 113	2830 ± 87	2523 ± 75	<0.05	−0.02
Dietary variety over 3 d	12.4 ± 0.5	15.5 ± 0.4	18.5 ± 0.4	22.2 ± 0.4	<0.001	0.71[2]
Outside HEI model						
Energy						
(kJ/d)	6781 ± 372	6718 ± 264	7418 ± 163	7556 ± 146	<0.05	0.21[2]
(kcal/d)	1620 ± 89	1605 ± 63	1772 ± 39	1805 ± 35	<0.05	0.21[2]
Carbohydrate (% of energy)	47.5 ± 1.0	52.8 ± 1.1	56.3 ± 0.8	60.4 ± 0.7	<0.001	0.48[2]
Vitamin C (mg/d)	49 ± 4	98 ± 8	139 ± 8	169 ± 7	<0.001	0.53[2]
Folate (μg/d)	145 ± 10	193 ± 17	257 ± 12	304 ± 10	<0.001	0.46[2]
β-Carotene (μg/d)	217 ± 42	548 ± 149	871 ± 346	806 ± 81	NS	0.09
Fiber (g/d)	10.1 ± 0.6	13.3 ± 0.7	17.9 ± 1.2	21.2 ± 0.7	<0.001	0.42[2]

[1] $\bar{x}$ ± SEM.
[2] $P < 0.05$.

TABLE 6
Healthy Eating Index (HEI) categories and plasma biomarker concentrations

Biomarker concentration	*n*	HEI score category: Poor diet <65	65–74	75–84	Good diet ≥85	Correlation with HEI (*r*)[1]
α-Carotene (μmol/L)	332	0.08	0.14	0.17	0.22	0.41[2]
β-Carotene (μmol/L)	333	0.49	0.52	0.68	0.85	0.30[2]
β-Cryptoxanthin (μmol/L)	333	0.11	0.19	0.23	0.25	0.40[2]
Lutein (μmol/L)	332	0.36	0.36	0.48	0.52	0.24[2]
Lycopene (μmol/L)	333	0.71	0.73	0.73	0.74	−0.02
Cholesterol (mmol/L)	332	5.76	5.62	5.40	5.65	−0.06
Vitamin C (μmol/L)	175	38.8	40.3	45.5	55.0	0.33[2]
Folate (nmol/L)	99	15.4	19.5	19.2	25.2	0.26[2]

[1] All biomarkers were log-transformed and all carotenoids were adjusted for cholesterol before the correlation analyses.
[2] $P < 0.05$.

DISCUSSION

The present study represents the first validation of HEI scores with use of plasma biomarkers of dietary exposure. Whereas earlier diet-quality indexes tended to focus on the fat and carbohydrate contents of diets (34), the HEI components include the consumption of the major food groups and a dietary variety score. HEI scores might thus be expected to show a modest degree of correlation with selected plasma biomarkers of vegetable and fruit consumption, as was indeed the case. Significant correlations were obtained between HEI scores and circulating plasma carotenoids, notably α-carotene, β-carotene, and β-cryptoxanthin, but not lycopene. Significant correlations were also obtained between HEI scores and plasma vitamin C concentrations. The correlations with plasma carotenoids and vitamin C remained after adjustment for age and vitamin supplement use in a regression model.

Plasma carotenoids are regarded as reliable biomarkers of vegetable consumption (24, 33). In clinical trials, β-carotene supplementation resulted in large increases in serum β-carotene concentrations (35). Human feeding studies also showed that plasma carotenoid concentrations increase after the consumption of carrots and other carotenoid-rich foods (36). Plasma vitamin C is regarded as a reliable biomarker of fruit consumption, particularly of citrus fruit and juices. HEI scores were positively correlated with plasma vitamin C and folate concentrations, both of which well reflect intakes (31, 33).

In the present sample of women, the total HEI score was most strongly correlated with dietary variety ($r = 0.71$) and with the consumption of fruit ($r = 0.57$). As expected, HEI scores were also strongly and negatively correlated with the consumption of fat ($r = -0.58$) and saturated fat ($r = -0.56$), expressed as a percentage of energy. Consumption of good diets, as opposed to poor diets, was associated with a sharp increase in the number of different foods eaten over 3 d; fruit consumption increased 6-fold in this time period. In contrast, the consumption of meat, milk, or grains increased relatively little in going from a poor to a good diet. These findings—that dietary variety and diet quality are closely correlated—argue for reinstatement of the dietary variety guideline in the *Dietary Guidelines for Americans*. Fruit consumption was another key aspect of a good diet, consistent with the aims and goals of the current dietary guidelines (15, 16).

Although the energy intakes of the women in the present study were similar to those of the general population of women, some of the food choices were not. Women aged 40–59 y in the 1994–1996 CSFII data set consumed a median of 6919 kJ/d (1653 kcal/d), 33% of energy from fat, 1.5 servings of fruit/d, and 3.2 servings of vegetables/d (37). The present respondents consumed less energy from fat (29%) and more servings of fruit (3.0) and vegetables (4.3) per day. In some studies of diet quality (38), elevated consumption of vegetables and fruit was linked with greater food costs.

Both eating habits and HEI scores are influenced by demographic and economic variables. The present sample was relatively homogeneous, being composed of white women with some college education and with household incomes in excess of the national median. Even so, significantly higher HEI scores were obtained for those women who were better educated, had higher incomes, and were more likely to be married. Past analyses of the CSFII data sets (14, 17) also showed that HEI scores were influenced by age, education level, and income level. Diet quality has been reported to vary with age and socioeconomic status (39), and the present data show that this trend was very robust and remained even for a homogeneous clinical sample of middle-income women.

If HEI scores are correlated with education and income levels, even for homogeneous samples, then respondents with widely divergent HEI scores may not have equivalent resources when it comes to spending on diet and health. The costs associated with food choices and health maintenance may affect chronic disease risk and disease outcomes. Epidemiologic studies routinely examine the effect of covariates in establishing correlations between diet and disease risk. Among such covariates are age,

TABLE 7
Regression coefficients for the Healthy Eating Index for each plasma biomarker, after adjustment for age and vitamin supplement use[1]

Plasma biomarker	Variable: Standard β coefficient	*P*	R^2
α-Carotene[2]	0.40	<0.001	0.18
β-Carotene[2]	0.28	<0.001	0.12
β-Cryptoxanthin[2]	0.41	<0.001	0.17
Lutein[2]	0.23	<0.001	0.06
Lycopene[2]	−0.00	NS	0.01
Vitamin C	0.26	<0.001	0.13
Folate	0.12	NS	0.28
Cholesterol	−0.13	<0.05	0.14

[1] All biomarkers were log-transformed.
[2] Adjusted for cholesterol concentrations.

TABLE 8
Mean Healthy Eating Index scores by sociodemographic variables[1]

Respondent characteristic	Value
Age (y)[2]	
20–39	74.1 ± 1.5 [54]
40–49	75.1 ± 1.1 [117]
50–59	79.2 ± 1.3 [102]
≥60	81.1 ± 1.2 [67]
Ethnicity	
White	77.6 ± 0.7 [309]
Nonwhite	75.2 ± 2.2 [31]
Education level[2]	
1–4 y of high school	72.4 ± 1.6 [66]
Some college	77.0 ± 1.3 [110]
College graduate	80.0 ± 1.4 [52]
Postgraduate	79.5 ± 1.0 [98]
Household income ($)[2]	
0–24 999	72.4 ± 2.0 [43]
25 000–39 999	75.9 ± 2.0 [51]
40 000–69 999	78.5 ± 1.2 [88]
≥70 000	79.1 ± 0.9 [130]
Marital status[2]	
Married	78.5 ± 0.7 [246]
Divorced, widowed, or separated	73.1 ± 1.7 [60]
Never married	76.4 ± 2.8 [25]
Vitamin supplement use	
Yes	79.4 ± 0.8 [227]
No	72.8 ± 1.2[3] [104]

[1] $\bar{x}$ ± SEM; *n* in brackets.
[2] *P* for trend < 0.05 (one-way ANOVA).
[3] Significantly different from yes, *P* < 0.05 (Student's *t* test).

smoking status, vitamin use, menopause, and history of disease (19). Confounding factors such as education level, income level, and the economics of food choice are regarded as being hard to measure (19) and are rarely part of any model. Because many health disparities are correlated with socioeconomic status, the question arises whether some of these disparities are due to income-mediated differences in the overall quality of the diet.

The key challenge in assessing diet quality lies in devising measures that can be linked to other aspects of a healthy diet, to some intermediate variables, or to appropriate health outcomes. The HEI is a single summary measure of diet quality that is both food- and nutrient-based. Such indexes capture the multidimensional nature of the diet better than do energy-adjusted intakes of a single nutrient, such as fat. However, food choices are often influenced by sociodemographic variables such as age, sex, ethnicity, education level, and income level. Although bread consumption is broadly distributed across all income groups, fresh fruit consumption is not. As a result, some of the HEI components may be more sensitive than are others to the economics of food choice. Multicomponent indexes of diet quality that encompass a broader range of foods and food groups are more likely to be affected by socioeconomic factors than is the single-nutrient approach. Analyses of correlations between diet and health should take economic factors into account.

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