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Healthy Eating Index Scores Are Associated with Blood Nutrient Concentrations in the Third National Health and Nutrition Examination Survey

STEPHANIE J. WEINSTEIN, PhD; TARA M. VOGT, MPH, PhD; SHIRLEY A. GERRIOR, PhD, RD

ABSTRACT
Objectives The Healthy Eating Index (HEI) is a summary measure of dietary quality, based on a 100-point scale. Our objectives were to assess the HEI as a measure of dietary status through its correlation with nutritional biomarkers and to identify those biomarkers most associated with diet quality and healthful food intake patterns.
Design National Health and Nutrition Examination Survey (NHANES) III, 1988-94.
Subjects Adults (≥17 years) with calculated HEI scores and blood nutrient data (n=16,467).
Statistical Analyses Performed Weighted crude and partial Pearson correlation coefficients (r) between HEI scores and blood nutrients were calculated. Geometric mean blood nutrient concentrations were calculated for five HEI score categories (ranging from ≤50 to >80).
Results HEI score was positively correlated with serum (r=0.25) and red blood cell (r=0.27) folate, serum vitamins C (r=0.30) and E (r=0.21), and all serum carotenoids except lycopene (r=0.17 to 0.27). These blood nutrient concentrations were 21% to 175% higher for participants in the highest HEI score group (>80) compared with those in the lowest group (≤50). Mean HEI scores were significantly (P<.0001) greater among the 42% of participants who took dietary supplements. Most correlations were attenuated when adjusted for additional factors.
Conclusions HEI score is correlated with a wide range of blood nutrients; the strongest relationships are with biomarkers of fruit and vegetable intake. These results are an important step in the validation of the HEI, emphasizing its potential as a tool for nutrition and health studies.
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S. J. Weinstein is a staff scientist with the Nutritional Epidemiology Branch, Division of Cancer Epidemiology and Genetics, National Cancer Institute, National Institutes of Health, Department of Health and Human Services, Bethesda, MD; at the time the study was conducted, she was a nutritionist with the Center for Nutrition Policy and Promotion, US Department of Agriculture, Alexandria, VA. T. M. Vogt is an Epidemic Intelligence Service officer with the Centers for Disease Control and Prevention, Division of Viral Hepatitis, National Center for Infectious Diseases, Atlanta, GA; at the time the study was conducted, she was a postdoctoral research fellow with the Nutritional Epidemiology Branch, Division of Cancer Epidemiology and Genetics, National Cancer Institute, National Institutes of Health, Department of Health and Human Services, Bethesda, MD. S.A. Gerrior is a nutritionist with the Center for Nutrition Policy and Promotion, US Department of Agriculture, Alexandria, VA.

Address correspondence to: Shirley A. Gerrior, PhD, RD, Center for Nutrition Policy and Promotion, US Department of Agriculture, 3101 Park Center Dr, Alexandria, VA 22302.

E-mail: shirley.gerrior@cnpp.usda.gov

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Many epidemiological studies that focus on the relationship between diet and risk of chronic disease examine the intake of a single nutrient, food, or food group. However, this approach does not consider the complexity of dietary behaviors, as foods and nutrients are not eaten in isolation (1). To address this issue, investigators are now including indexes of dietary quality, patterns, and variety in their research (see, for example, [2-7]). These indexes are generally based on dietary recommendations designed to reduce the risk of chronic disease.

One such index, the Healthy Eating Index (HEI), was developed by the US Department of Agriculture's (USDA) Center for Nutrition Policy and Promotion to assess how well American diets conform to dietary recommendations (8). It was intended as a basis for nutrition education and health promotion activities and as the primary tool for monitoring changes in consumption patterns and dietary quality of Americans over time (9). The HEI is based on specific recommendations in the Dietary Guidelines for Americans (10) and the Food Guide Pyramid (11), which translates the Guidelines into practice. The HEI incorporates nutrient requirements and dietary guidelines into one single, summary measure. It was developed based on a 10-component system of five food groups, four nutrients, and a measure of variety in food intake. Each of the 10 components has a score ranging from zero to 10, with a total possible index score of 100. Because of its composite nature, the HEI may capture the multidimensional character of the diet better than any single nutrient (12), therefore addressing the complexity of dietary behavior and serving as a potentially useful tool for epidemiological research.

The HEI was originally calculated using the 1989-90 Continuing Survey of Food Intakes by Individuals (CSFII), and later updated using the 1994-96 CSFII. Based on 1 day of dietary intake, the mean HEI increased from 61.4 in 1989 (8) to 63.8 in 1996 (13). The HEI was also calculated using data from the third National Health and Nutrition Examination Survey (NHANES III, 1988-94) and NHANES 1999-2000. For both of these, the mean HEI score was also 63.8, although individual component scores differed (14,15).

Since its release, the HEI has had a wide range of applications. It has been used to examine the demographics associated with healthful eating (16), to explore consumers' misperceptions of their diet quality (17), to measure the success of dietary interventions in schools (18), to assess diet quality and adequacy of older adults (19,20), and to assess the health and nutrition of popular diets (21). A version of the HEI calculated from food frequency questionnaires was associated with a lower risk of cardiovascular disease in men, but was only weakly associated with lower risk in women, and was not associated with cancer risk (22,23). An interactive version of the HEI, available at www.cnpp.usda.gov, provides a quick summary measure of a person's diet quality and offers relevant links to health information.

The HEI and other similar indices are based on dietary intake data gathered using standard instruments such as food frequency questionnaires and 24-hour dietary recalls. However, these instruments have recognized limitations due to, for example, over- or underreporting of intake, variation in nutrient content of individual foods, differing bioavailability of nutrients in different foods, and incomplete food composition databases, and are thus subject to errors (1,24,25). Investigators have therefore been incorporating biomarkers of dietary intake into nutritional epidemiology studies. Biomarkers may provide a more accurate and objective measure of dietary intake (26) and enable better identification of diet–disease relationships.

Previous research by USDA using 1989-90 CSFII data (8,9) showed positive correlations between HEI scores and intakes of a number of nutrients; however, correlations between HEI scores and biomarkers for nutrient intakes could not be examined because the CSFII did not collect biological samples. Using NHANES III, we examined the relationship between HEI scores and biologic measures of nutrient status among a large, nationally representative sample of the US population. The objectives of this research were to assess the HEI as a measure of dietary status through its correlation with nutritional biomarkers, and to identify those biomarkers most associated with diet quality and healthful food patterns.

MATERIALS AND METHODS

Data Source

NHANES III was conducted from 1988 to 1994 by the National Center for Health Statistics (NCHS), Centers for Disease Control and Prevention, and was designed to describe the health and nutritional status of the US civilian noninstitutionalized population. The survey included a nationally representative, multistage, stratified probability sample of the US population aged ≥2 months living in households. Children aged 2 months to 5 years and persons aged ≥60 years were oversampled, as were African Americans and Mexican Americans. The survey included a household interview, physical examination, 24-hour dietary recall, and blood draw (27,28). Data and documentation for our study were provided by NCHS, including HEI scores, which were calculated from the 24-hour recalls (14,29,30). Most nutrient intake variables used in this analysis were those derived by NCHS from the USDA database (Phase 1 [1993] and Phase 2 [1995], Riverdale, MD), with the exception of selenium, beta carotene and vitamin D, which NCHS derived from the University of Minnesota Nutrition Coordinating Center Nutrient Database (versions 15 to 27, 1996, Minneapolis, MN).

Subjects

All adult participants in NHANES III, aged 17 years and older, who had available laboratory nutrient data as well as calculated HEI scores were included in the analyses (n=16,467). For each particular nutrient, between 195 and 814 subjects were missing nutrient data, so individual analyses were conducted with between 15,654 and 16,273 subjects. Vitamin B-12 and homocysteine were measured only in the second phase of NHANES III (1991-94); therefore, data are available for only 8,267 and 7,269 persons for these respective analyses. Furthermore, because of recommended restrictions on the use of low-density lipoprotein (LDL) and triglyceride data, these two analyses include only 6,979 persons.

HEI Scores

HEI scores range from zero to 100, with 10 equally weighted components, each with a score ranging from zero to 10. The first five components of the HEI measure the degree to which a person's diet conforms to the Food Guide Pyramid's recommended number of servings, based on age and gender, of grains, fruits, vegetables, meats, and dairy products (Table 1). The maximum score of 10 indicates that the recommended servings were reached, while a zero indicates that no foods in that group were consumed. Intermediate scores are calculated proportionally. The next four components measure compliance on recommended intakes of total fat, saturated fat,

Table 1. Recommended number of US Department of Agriculture Food Guide Pyramid servings per day, by age and gender categories[a]

Category	Energy (kcal)	No. grain servings	No. vegetable servings	No. fruit servings	No. milk servings	No. meat servings
Children 2-3 years[b]	1,300	6.0	3.0	2.0	2.0	2.0
Recommended[c]	1,600	6.0	3.0	2.0	2.0	2.0
Children 4-6 years	1,800	7.0	3.3	2.3	2.0	2.1
Females 51+ years	1,900	7.4	3.5	2.5	2.0	2.2
Children 7-10 years	2,000	7.8	3.7	2.7	2.0	2.3
Females 11-24 years	2,200	9.0	4.0	3.0	3.0	2.4
Recommended[c]	2,200	9.0	4.0	3.0	2.0	2.4
Females 25-50 years	2,200	9.0	4.0	3.0	2.0	2.4
Males 51+ years	2,300	9.1	4.2	3.2	2.0	2.5
Males 11-14 years	2,500	9.9	4.5	3.5	3.0	2.6
Recommended[c]	2,800	11.0	5.0	4.0	2.0	2.8
Males 19-24 years	2,900	11.0	5.0	4.0	3.0	2.8
Males 25-50 years	2,900	11.0	5.0	4.0	2.0	2.8
Males 15-18 years	3,000	11.0	5.0	4.0	3.0	2.8

[a]Source: reference (13).
[b]For children aged 2 to 3 years, portion sizes for all groups except milk were reduced to two thirds of adult servings.
[c]Recommended number of servings per day at food energy levels specified in the Food Guide Pyramid (11).

Table 2. Criteria for minimum and maximum scores for each HEI[a] component[bc]

Component	Criteria for minimum score (0)	Criteria for maximum score (10)[d]
Grain consumption	0 servings	6-11 servings[e]
Vegetable consumption	0 servings	3-5 servings[e]
Fruit consumption	0 servings	2-4 servings[e]
Milk consumption	0 servings	2-3 servings[e]
Meat consumption	0 servings	2-3 servings[e]
Total fat intake	≥45% of kcal	≤30% of kcal
Saturated fat intake	≥15% of kcal	<10% of kcal
Cholesterol intake	≥450 mg	≤300 mg
Sodium intake	≥4,800 mg	≤2,400 mg
Food variety	≤3 items/d	≥8 items/d

[a]HEI=Healthy Eating Index.
[b]Proportional scores were assigned to consumption levels between the minimum and maximum range.
[c]Source: reference (13).
[d]The maximum total HEI score is 100.
[e]Number of servings depends on recommended Food Guide Pyramid servings (see Table 1).

cholesterol, and sodium. A score of 10 on these components is reached by consuming at or below the maximum recommended levels. The final component is a measure of dietary variety. See Table 2 for the scoring criteria for each component. Table 3 shows the HEI scores from CSFII 1989 and 1996, NHANES III (1988-94), and NHANES 1999-2000.

Biological Component

NHANES III includes data on an array of biological specimens; the current study examined serum vitamins A (retinol), B-12, C (ascorbic acid), D (25-hydroxyvitamin D), and E (α-tocopherol); serum and red blood cell (RBC) folate; and serum carotenoids (α-carotene, β-carotene, β-cryptoxanthin, lutein/zeaxanthin, lycopene), selenium, ferritin, cholesterol (total, high-density lipoprotein [HDL], and LDL), triglycerides, and homocysteine. Laboratory procedures have been documented elsewhere (31).

Per instructions in the NHANES laboratory documentation (29), triglyceride values were only included if subjects reported fasting at least 9 hours before blood draw, were examined in the morning, and were randomly assigned to the morning fasting sample. Serum LDL values were calculated by NCHS using total cholesterol, HDL cholesterol, and triglyceride values, and therefore had these same restrictions. In addition, LDL values were not included when triglycerides exceeded 400 mg/dL (29).

Statistical Analyses

Sample weights provided by NCHS were used to obtain results generalizable to the US population, and SUDAAN statistical software (release 8.0, 2001, Research Triangle Institute, Research Triangle Park, NC) was used to account for the complex sampling design.

For the purpose of this analysis, HEI scores were analyzed continuously and were categorized into five groups (≤50, 51 to 60, 61 to 70, 71 to 80, and >80) to maintain consistency with previous publications (8). Using SUDAAN, geometric means for each blood nutrient were calculated by HEI score group.

Weighted Pearson correlation coefficients (r) between HEI score and blood nutrients, and between HEI score and nutrient intakes, were calculated using SAS (version 8.2 TS2MO, 1999-2001, SAS Institute, Cary, NC). The P values were calculated from unadjusted, weighted regression models with HEI score as the independent variable and each particular nutrient as the dependent variable.

Table 3. Component and overall HEI[a] scores from CSFII[b] and NHANES[cd]				
Component	**CSFII 1989[e]**	**CSFII 1996[f]**	**NHANES III 1988-94[g]**	**NHANES 1999-2000[h]**
Sample size	3,997	4,800	26,348	8,070
Grain	6.1	6.7	6.7	6.7
Vegetables	5.9	6.3	5.7	6.0
Fruits	3.7	3.8	3.8	3.8
Milk	6.2	5.4	6.6	5.9
Meat	7.1	6.4	6.8	6.6
Total fat	6.3	6.9	6.5	6.9
Saturated fat	5.4	6.4	6.1	6.5
Cholesterol	7.5	7.9	7.8	7.7
Sodium	6.7	6.3	6.0	6.0
Variety	6.6	7.6	7.7	7.7
Total[i]	61.4	63.8	63.8	63.8

[a]HEI=Healthy Eating Index.
[b]CSFII=Continuing Survey of Food Intakes by Individuals.
[c]NHANES=National Health and Nutrition Examination Survey.
[d]Based on one day of dietary intake, for individuals 2 years and older.
[e]Source: reference (8).
[f]Source: reference (13).
[g]Source: reference (14).
[h]Source: reference (15).
[i]Total does not equal sum of scores due to rounding.

Because nutrient intakes tend to be positively correlated with total energy intake, nutrient intakes were also adjusted for total energy intake using the residual method recommended by Willett and Stampfer (32). Energy-adjusted intakes are calculated as the residuals from a regression model with total energy intake as the independent variable and nutrient intake as the dependent variable. A constant value (the mean of the nutrient intake) is then added to the residuals so that the units make intuitive sense (32). Because carotenoids and vitamin E are transported by plasma lipoproteins, lipoprotein variability can result in extraneous variation in these nutrients (24,33). Therefore, these particular analyses were adjusted by including total cholesterol in the correlation models. For geometric mean calculations, values were adjusted for total cholesterol using the residual method as described, substituting total cholesterol for total energy.

Weighted partial Pearson correlation coefficients (r) were calculated using SAS to assess the association between HEI score and blood nutrients while adjusting for the influence of other important predictors of blood nutrient concentrations. Potential confounding variables were those previously identified as related to the HEI (8,13,16) and others that could plausibly impact blood nutrient concentrations, and included age, race/ethnicity, sex, census region, poverty income ratio, pregnancy, body mass index, energy intake, alcohol intake, smoking, and vitamin or mineral supplement use. To identify which potential confounders to include, all variables were entered into multiple linear regression models developed with SUDAAN, and were retained if their removal changed the HEI score β-coefficient by $>10\%$. With the exception of poverty income ratio and pregnancy, all variables were confounders in at least one blood nutrient model and, for consistency, were included in all models. The P values for the partial correlations were derived from these regression models.

RESULTS

Blood Nutrients

Geometric mean blood nutrient concentrations for each HEI score group and correlations between blood nutrient concentrations and HEI score are presented in Table 4. Serum and RBC folate values were both positively correlated with HEI score (r=0.25 and 0.27, respectively). Serum folate concentrations were 90% higher and RBC folate concentrations were 55% higher for participants in the highest HEI score group (>80) compared with those in the lowest group (≤50). Neither serum vitamin B-12 nor homocysteine were correlated with HEI score.

Serum vitamins C and E were both positively correlated with HEI score (r=0.30 and 0.21, respectively), and the concentrations were 148% and 21% higher, respectively, for participants in the highest HEI score group compared with those in the lowest group (Table 4). Serum vitamin A was not correlated with HEI score. All of the carotenoids, except lycopene, were positively correlated with HEI score (r=0.17 to 0.27, 32% to 175% higher for participants in highest compared with lowest HEI score group).

Cholesterol (total, HDL, and LDL), triglyceride, vitamin D, ferritin, selenium, and total calcium level were not correlated with HEI score (Table 4). All correlations were re-run using only subjects who reported fasting more than 6 hours before blood draw and results were unchanged (no correlation changed by more than 0.01). Most correlations were attenuated when adjusted for additional factors (see partial correlations, Table 4).

Table 4. Geometric mean blood nutrient concentrations of adult participants in NHANES III[a] by HEI[b] score groups and crude and partial correlations between blood nutrients and HEI score

Blood nutrients[c]	No.	Geometric Means by HEI Score Groups					Crude correlation with HEI	Partial correlation with HEI[d]
		≤50	51-60	61-70	71-80	>80		
Serum folate (nmol/L)	16,264	10	11	12	15	19	.25**	.15**
Red blood cell folate (nmol/L)	16,273	340	364	395	448	526	.27**	.16**
Serum vitamin B-12 (pmol/L)	8,267	315	315	310	334	334	.02**	.01*
Serum homocysteine (μmol/L)	7,269	9.18	9.25	8.96	8.60	8.51	−.07**	−.06**
Serum vitamin C (μmol/L)	15,654	21	27	33	40	52	.30**	.21**
Serum vitamin E (μmol/L)	16,110	24	24	25	27	29	.21**	.13**
Serum vitamin A (μmol/L)	16,110	1.91	1.93	1.96	2.00	2.10	.10**	.05**
Serum α-carotene (μmol/L)	16,110	0.04	0.05	0.06	0.08	0.11	.27**	.20**
Serum β-carotene (μmol/L)	16,110	0.21	0.24	0.27	0.32	0.42	.21**	.12**
Serum β-cryptoxanthin (μmol/L)	16,109	0.11	0.12	0.14	0.15	0.19	.24**	.20**
Serum lutein/zeaxanthin (μmol/L)	16,110	0.31	0.32	0.34	0.36	0.41	.17**	.12**
Serum lycopene (μmol/L)	16,110	0.38	0.40	0.39	0.37	0.36	−.03**	.03**
Serum cholesterol (mmol/L)	16,200	5.09	5.07	5.08	5.14	5.30	.06**	−.02*
Serum low-density lipoprotein cholesterol (mmol/L)	6,979	3.17	3.06	3.07	3.12	3.21	.01	−.04**
Serum high-density lipoprotein cholesterol (mmol/L)	16,087	1.21	1.27	1.25	1.26	1.29	.04**	−.04**
Serum triglycerides (mmol/L)	6,979	1.19	1.19	1.21	1.28	1.35	.08**	.06*
Serum vitamin D (nmol/L)	16,264	68	67	68	68	72	.02	.04
Serum ferritin (μg/L)	16,259	80	78	75	77	78	−.02	−.03
Serum selenium (nmol/L)	15,899	1.57	1.57	1.58	1.58	1.59	.03*	.02
Serum total calcium (mmol/L)	16,065	2.30	2.30	2.31	2.31	2.30	−.005	.004

[a]NHANES=National Health and Nutrition Examination Survey.
[b]HEI=Healthy Eating Index.
[c]To convert nmol/L folate to ng/mL, multiply nmol/L by 0.441. To convert ng/mL folate to nmol/L, multiply ng/mL by 2.266. To convert pmol/L B-12 to pg/mL, multiply pmol/L by 1.355. To convert pg/mL B-12 to pmol/L, multiply pg/mL by 0.7378. To convert μmol/L vitamin C to mg/dL, multiply μmol/L by 0.018. To convert mg/dL vitamin C to μmol/L, multiply mg/dL by 56.78. To convert μmol/L vitamin E to mg/dL, multiply μmol/L by 0.043. To convert mg/dL vitamin E to μmol/L, multiply mg/dL by 23.22. To convert μmol/L vitamin A to μg/dL, multiply μmol/L by 28.65. To convert μg/dL vitamin A to μmol/L, multiply μg/dL by 0.035. To convert μmol/L α-carotene, β-carotene, or lycopene to μg/dL, multiply μmol/L by 53.68. To convert μg/dL α-carotene, β-carotene, or lycopene to μmol/L, multiply μg/dL by 0.01863. To convert μmol/L β-cryptoxanthin to μg/dL, multiply μmol/L by 55.29. To convert μg/dL β-cryptoxanthin to μmol/L, multiply μg/dL by 0.01809. To convert μmol/L lutein/zeaxanthin to μg/dL, multiply μmol/L by 56.89. To convert μg/dL lutein/zeaxanthin to μmol/L, multiply μg/dL by 0.01758. To convert mmol/L low-density lipoprotein, high-density lipoprotein, or total cholesterol to mg/dL, multiply mmol/L by 38.7. To convert mg/dL low-density lipoprotein, high-density lipoprotein, or total cholesterol to mmol/L, multiply mg/dL by 0.026. To convert mmol/L triglycerides to mg/dL, multiply mmol/L by 88.6. To convert mg/dL triglycerides to mmol/L, multiply mg/dL by 0.0113. To convert nmol/L vitamin D to ng/mL, multiply nmol/L by 0.401. To convert ng/mL vitamin D to nmol/L, multiply ng/mL by 2.496. To convert μg/L ferritin to ng/mL, multiply μg/L by 1.0. To convert ng/mL ferritin to μg/L, multiply ng/dL by 1.0. To convert μmol/L selenium to μg/mL, multiply μmol/L by 0.079. To convert μg/mL selenium to μmol/L, multiply μg/mL by 12.66. To convert mmol/L calcium to mg/dL, multiply mmol/L by 4.01. To convert mg/dL calcium to mmol/L, multiply mg/dL by 0.250.
[d]Partial correlations are adjusted for age, race/ethnicity, sex, vitamin or mineral supplement use, BMI, energy intake, smoking, alcohol intake, and region. Vitamin E and carotenoids are also adjusted for cholesterol.
**P*<.05. ***P*<.01. *P* values are calculated from weighted crude and adjusted regression model.

Vitamin and Mineral Supplements

Approximately 42% of participants indicated they had taken vitamin or mineral supplements in the past month. As HEI score increased, the percent of participants who took supplements also increased. For HEI scores ≤50, 51 to 60, 61 to 70, 71 to 80, and >80, the percent of supplement users was 33.4%, 36.4%, 40.7%, 47.9%, and 56.1%, respectively. Furthermore, the mean HEI score was significantly ($P<.0001$) greater among supplement users (65.8) than among nonusers (61.8).

Because of the strong relationship between HEI score and supplement use, crude correlations were re-run using only subjects who reported not taking a supplement in the past month. Results were basically unchanged (no correlation changed by more than 0.03, with the exception of RBC folate for which the correlation decreased from 0.27 to 0.22).

Nutrient Intakes

With the exception of vitamin E, the correlations between HEI score and nutrient intakes were either similar to or stronger than the correlations between HEI score and blood nutrients (Table 5). With energy adjustment, the correlations for β-carotene, iron, folic acid, and cholesterol increased to 0.26, 0.28, 0.33, and −0.35 respectively, while for the other nutrients correlations were unchanged or slightly increased (by 0.01 to 0.02).

DISCUSSION

This study examined the relationship between diet quality, as quantified by the HEI, and selected biomarkers of dietary intake. The use of biomarkers in this study served as an important step in the validation of the HEI and emphasized the potential of the HEI to be used in epide-

Table 5. Correlations between nutrient intakes and HEI[a] score in NHANES III[b]

Dietary nutrients	Correlation with HEI
Selenium (μg)	0.02
Vitamin B-12 (μg)	−0.03
Vitamin E (Total α-tocopherol equivalents, mg)	0.08
Vitamin D (μg)	0.09
Calcium (mg)	0.09
Total vitamin A (retinol equivalents)	0.16
β-carotene (μg)	0.22
Total vitamin A (IU)	0.23
Iron (mg)	0.23
Folic acid (μg)	0.29
Cholesterol (mg)	−0.29
Vitamin C (mg)	0.33

[a]HEI=Healthy Eating Index.
[b]NHANES=National Health and Nutrition Examination Survey.

miological studies of dietary intake and risk of chronic disease. HEI scores were correlated with serum and RBC folate, vitamins C and E, and all carotenoids except lycopene, and the mean concentrations of these nutrients increased with increasing HEI score groupings. The partial correlations were attenuated when compared with the crude correlations, indicating that part of the correlation can be attributed to these other factors, which are associated with both the HEI score and the blood nutrients.

The biomarkers that were associated with HEI scores in this study were somewhat limited in scope, with most representing the nutrients found in fruits and vegetables, rather than those found in meat, milk, or grain products. It is expected that fruit and vegetable consumption, and biomarkers of fruit and vegetable consumption, might correlate with overall HEI scores for a number of reasons. First, two of the 10 HEI component scores are based on intakes of fruits and vegetables, and the dietary variety component has the potential to be influenced by consumption of different kinds of fruits and vegetables. In addition, a diet rich in fruits and vegetables is usually lower in total fat, saturated fat, cholesterol, and sodium, and each of these factors contribute to an HEI component. The fruit and vegetable components of the HEI were in fact correlated with total HEI in this dataset (r=0.59 and 0.38, respectively), while similar correlations were found in another study (r=0.57 and 0.29, respectively) (12). Carotenoids, folate, and vitamin C are largely found in fruits and vegetables, and blood concentrations of these nutrients may be reliable markers for fruit and vegetable intake (34-38). Not surprisingly, we found that these fruit and vegetable biomarkers in NHANES III were positively correlated with overall HEI scores, indicating that the HEI can be a good indicator of status of these nutrients. High fruit and vegetable intake has been associated with decreased risks of various cancers, heart disease, stroke, and possibly other chronic diseases (39-43) and is encouraged by the Dietary Guidelines for Americans (44), the USDA Food Guide Pyramid (11), and the 5 A Day program (45).

The fact that HEI scores were correlated with intakes of all carotenoids except lycopene is not unexpected. Lycopene is found in high concentrations in tomato-based products, such as catsup, pizza, marinara sauce, tomato soup, and canned tomato products, which tend to be low in content of the other carotenoids (46). Foods that are good sources of the other carotenoids but contain no lycopene include, for example, cooked broccoli, raw baby carrots, cooked collards, cantaloupe, red pepper, and cooked spinach (46). Consumption of lycopene-rich foods may result in low HEI scores because these foods may contribute little to the vegetable component score and may be high in sodium and/or fat, thereby negatively affecting these HEI component scores.

HEI scores were not associated with all nutrients examined; however, in most cases this is not surprising. For example, circulating levels of vitamin D are influenced by sunlight exposure in addition to dietary intake (47). Serum ferritin, which may provide the best biochemical indicator of iron stores, is not highly correlated with total iron intake (24); growth requirements, blood loss, and intake of other foods are all important influences on serum ferritin concentrations (24). Serum selenium concentrations are a good indicator of selenium intake; however, it is difficult to quantify selenium intake because the selenium content of foods varies widely (48). Finally, serum calcium and vitamin A concentrations are well controlled homeostatically and are not good indicators of intake (49).

The use of biomarkers in this study served as an important step in the validation of the HEI and emphasized the potential of the HEI to be used in epidemiological studies of dietary intake and risk of chronic disease.

Mean HEI scores were significantly greater among vitamin and mineral supplement users compared with nonusers. In general, supplement users tend to consume more nutritious diets than nonusers and to practice other healthful behaviors (50-53). To reduce potential confounding by supplement use, we re-ran the crude correlations using only subjects who reported no supplement use, but found no important change in the results. We also adjusted for supplement use in partial correlations. However, our measure of vitamin supplement use was based on only one question, and it is possible that residual confounding by supplement use accounts for some of the association found between HEI score and blood nutrient levels.

Although the correlations between HEI scores and blood nutrient concentrations in this study are no greater than 0.30, the correlations between nutrient intakes and blood nutrients in NHANES III are also modest. For example, for adults aged 20 to 59 years, Dixon and colleagues (54) report correlations for serum and RBC folate vs folate intake of 0.24 and 0.21, respectively, and for serum vs intake of vitamins A, B-12, C, and E they report correlations of 0.15, 0.08, 0.31, and 0.06, respectively (54). For serum carotenoids (except lycopene), they report correlations with intakes of fruits and fruit juices, vegetables, dark green leafy vegetables, and deep orange/yellow vegetables to range between 0.03 and 0.35, and for lycopene to range between −0.02 and 0.02 (54).

The true correlations between HEI and blood nutrients may have been attenuated due to day-to-day variability in the HEI and/or the biomarker concentrations (55) and could, in fact, be higher than those reported. However, this variability, as well as potential measurement error, could attenuate any relative risks that are calculated between HEI scores and disease outcomes.

Many of the correlations between HEI score and nutrient intakes reported in the CSFII (8) were slightly stronger than what we observed in NHANES III. In addition, we found that the HEI was more highly correlated with nutrient intakes than with blood nutrients in NHANES III, but this is expected because the data used to calculate the HEI are derived from the same 24-hour recall as the data used to calculate nutrient intakes. Nevertheless, it is encouraging that HEI scores were correlated with blood nutrients, as blood nutrient concentrations may be more representative of actual nutrient status than dietary intake measures (26).

Similar findings on the relationship between blood biomarkers and HEI scores have been reported in a sample of 340 women enrolled in a case-control study of breast cancer (12). HEI scores were significantly ($P<.05$) correlated with plasma α carotene (r=0.41), β-carotene (r=0.30), β-cryptoxanthin (r=0.40), lutein (r=0.24), vitamin C (r=0.33), and folate (r=0.26), but not lycopene (r= −0.02) or cholesterol (r=−0.06). Our study expands on this smaller study by including a large, representative sample of adult men and women in the United States and by examining a greater number of nutritional biomarkers.

CONCLUSIONS

This research provides nutrition professionals with additional information on how well the HEI reflects dietary status. The HEI was correlated with a variety of blood nutrients, but the strongest associations were with biomarkers of fruit and vegetable consumption. Dietetics practitioners may use the HEI to assess overall diet quality in persons, and researchers may use the HEI as a measure of dietary quality in studies of diet and chronic disease. This may be especially useful when blood nutrient data are not available. The HEI is an instrument that incorporates many aspects of diet and is related to a number of biomarkers that are being studied for their relation to chronic disease risk.

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