Reproducibility and validity of the Diet Quality Index Revised as assessed by use of a food-frequency questionnaire[1–3]

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ABSTRACT

Background: The Diet Quality Index Revised (DQI-R) is a dietary assessment instrument based on 10 dietary recommendations reflecting dietary guidelines and policy in the United States.

Objective: The objective of this study was to assess the reproducibility and validity of the DQI-R as measured by use of food-frequency questionnaires (FFQs).

Design: Diet was assessed separately by two FFQs at a 1-y interval and by two 1-wk diet records. DQI-R scores were computed from each method. Venous blood specimens were collected for measurement of dietary biomarkers. Participants ($n = 127$) were men aged 40–75 y in a validation study of the Health Professionals Follow-up Study.

Results: Mean DQI-R scores were 69.5 for FFQ-1, 67.2 for FFQ-2, and 62.0 for the diet records out of a possible score of 100. The reproducibility correlation for the 2 FFQ scores was 0.72. Correlations between scores for each of the 2 FFQs and diet records were 0.66 (FFQ-1) and 0.72 (FFQ-2). DQI-R scores from FFQ-2 were directly correlated with plasma biochemical measurements of α-carotene ($r = 0.43$, $P < 0.0005$), β-carotene ($r = 0.35$, $P < 0.005$), lutein ($r = 0.31$, $P < 0.005$), and α-tocopherol ($r = 0.25$, $P < 0.05$) and were inversely correlated with plasma total cholesterol ($r = -0.22$, $P < 0.05$).

Conclusions: These data indicate reasonable reproducibility and validity of the DQI-R as assessed by an FFQ. Future studies are needed to examine whether this index and other instruments of diet quality can reliably predict disease outcomes. *Am J Clin Nutr* 2003;78:941–9.

KEY WORDS Diet index, diet quality, dietary pattern, biomarker, reproducibility, validity

INTRODUCTION

Traditional nutritional epidemiologic studies usually focus on the effects of single nutrients or foods. The measurement of overall diet quality has been suggested as an alternative method to assess diet-disease relations (1–4), yet few tools designed to measure diet quality have been tested for their reproducibility or validity. Assessing diet quality requires focusing on the nutritional elements considered most important in relation to health promotion and disease prevention (5–9); nutritional constructs such as dietary variety or diversity may also be considered (10–18).

One methodologic approach to the measurement of total diet quality uses an index, in which separate nutritional elements or constructs are combined into a single score (1–4). The Diet Quality Index (DQI) is an instrument developed to measure overall diet quality that reflects a risk gradient for diet-related chronic disease (4). The original DQI is based on recommendations made in *Diet and Health: Implications for Reducing Chronic Disease Risk* (19) and consists of 8 dietary variables (total fat, saturated fat, cholesterol, fruit and vegetables, grains and legumes, protein, sodium, and calcium) that are summed into a composite diet quality score. Scores range from 0 to 16, where 0 reflects the highest quality diet and 16 the lowest. Comparing the original DQI with components not included in the index indicated strong relations between a low DQI score (excellent diet) and high fiber and vitamin C intakes (4).

The index was subsequently updated (20) to reflect additional aspects of diet quality not addressed in the original index, including variety, moderation, and proportionality, as reflected in the *Food Guide Pyramid* (21) and the *Dietary Guidelines for Americans* (5th edition) (22), as well as changes in nutritional recommendations and policy [eg, the score for the calcium component was changed from being based on the recommended dietary allowances (23) to being based on the dietary reference intakes (DRIs; 24)]. The Diet Quality Index Revised (DQI-R) includes 10 components, 4 of which are the same as in the original DQI (total fat, saturated fat, cholesterol, and calcium). The fruit and vegetable component is now 2 separate components, grains is its own category, and iron replaces protein. Dietary moderation and diversity are 2 new components. DQI-R scores range from 0 to 10 for each component, for a highest possible diet quality score of 100. Among a representative sample of 3202 adults participating in the 1994 Continuing Survey of Food Intakes by Individuals who had

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completed two 24-h recalls, higher DQI-R scores were related to lower fat consumption, higher fruit and vegetable intakes, and higher iron and calcium intakes (20).

To our knowledge, the reproducibility of the DQI-R and its comparability across dietary assessment methods have not been assessed. Establishing the validity of this index will help to demonstrate its utility in assessing diet quality and hence its potential use in assessing diet and disease associations. The objective of our study was to assess the reproducibility and validity of the DQI-R as measured by use of food-frequency questionnaires (FFQs) among male health professionals.

SUBJECTS AND METHODS

Study population

Participants in this study were a subsample of 127 men aged 40–75 y who participated in the Health Professionals Follow-up Study, a prospective cohort study that began in 1986 and included 51 529 male dentists, pharmacists, optometrists, osteopathic physicians, podiatrists, and veterinarians; this study has been described elsewhere (25). In brief, in 1987 a random sample of 323 men was asked to participate in a dietary validation study, of which 157 agreed. Men who did not complete the 2 wk of diet records ($n = 17$) or the second FFQ ($n = 5$), left more than 70 items blank on either FFQ ($n = 1$), or reported implausible energy intake on either FFQ (outside the range of 3347–17 573 kJ/d, or 800–4200 kcal/d; $n = 7$) were excluded, leaving 127 (39%) participants with complete information for 2 wk of diet records and both FFQs for the analysis (26).

Dietary assessment

The 127 men in the diet validation study completed FFQs at baseline in 1986 (FFQ-1) and again in 1987 (FFQ-2), roughly 1 y apart, as well as two 1-wk diet records <7 mo apart during the year between the 2 FFQs. To complete the diet records, the participants were contacted by a research dietitian and provided detailed instruction on how to record diet intake by using specially designed booklets and scales to weigh foods. Records were individually reviewed and the participants were re-contacted to provide further detail when necessary. The reproducibility and validity of nutrient intakes (26), food intakes (27), and dietary patterns as measured by factor analysis (28) have been described elsewhere.

The FFQ included 131 food items that were selected to describe usual dietary intake over the past year. Participants were asked to describe their average intake of each food by using 9 frequency of consumption categories ranging from "almost never" to "≥ 6 times/d." For FFQ-1, 35% of subjects had complete FFQs, with no missing food items; 76% of subjects had no more than 3 missing food items; and 8 subjects (6%) were missing > 10% of items. For FFQ-2, 39% of subjects had complete FFQs, with no missing food items; 91% of subjects had no more than 3 missing food items, and 4 subjects (3%) were missing > 10% of items. Food items that were not answered on the FFQ were considered to reflect nonconsumption and were recoded as "almost never."

Dietary data from the FFQ were converted to average daily intake values (eg, 1 serving/wk = 0.14 serving/d). Serving size definitions for the FFQ were based on "natural" portions (eg, 1 slice of bread) or typical serving sizes (21, 29); as aforementioned, scales were provided to participants to weigh and record food for the diet records. On the 2 wk of diet records, there were 1565 unique foods reported; mixed dishes were converted to recipes to obtain food ingredient data (27). The average daily intake from the two 1-wk diet records was calculated and used in all analyses to reduce the effect of within-person variation in daily food consumption.

Daily food intake data were grouped into the food-based DQI-R dietary components, and the DQI-R nutrient components were assessed directly (29). According to the method of Haines et al (20), the total fat, saturated fat, and cholesterol components were calculated as a percentage of total energy and were categorically scored as 0, 5, or 10, and the remaining components were scored as continuous variables from 0 to 10, proportional to the recommended range of intake. Scores were summed across the 10 components for a highest possible score of 100 points.

The goals for the fruit, vegetable, grain, and added sugar components as defined by the food guide pyramid (21) depend on daily energy intake. In our study population, most of the participants (> 80%) reported energy intakes between 7531 and 10 878 kJ/d (1800–2600 kcal/d), with a mean close to 9205 kJ/d (2200 kcal/d) from the average of the 2 wk of diet records and the FFQs, so we used the recommendations for this energy range. The fruit and vegetable components included fresh, canned, and dried fruit and vegetables and juices. The grains component included breads, grains, cereals, rice, pasta, popcorn, and crackers. According to the method of Haines et al (20), sweets such as pies, cakes, cookies, and pastries were excluded from the grains score, although these foods are considered part of the grains food group in the food guide pyramid.

The DQI-R components for cholesterol, calcium, and iron were not adjusted for total energy because the cutoffs for intakes used in the DQI-R are not energy dependent. The adequate intake (23) for calcium and the recommended dietary allowance for iron (23) are age dependent, and age-specific cutoffs are indicated in the footnotes to **Table 1**.

DQI-R dietary diversity component

The method used to calculate dietary diversity in this study was slightly modified from the method used by Haines et al (20). In our study, a 131-item FFQ was used to assess usual consumption, from which average daily servings were estimated. Average daily servings were also estimated from the diet records. The 4 major food groups (grains, vegetables, fruit, and meat and dairy) were divided into several subgroups, and all foods were assigned to one of these subgroups (**Appendix A**).

Because Haines et al (20) used a diversity cutoff of 1/2 serving/d over a 2-d period, we thought it most comparable if we halved the cutoff in our study to 1/4 serving/d, because the FFQ (and the mean of the diet records) provided us with daily estimates (ie, 1/2 serving per 2-d period = 1/4 serving per 1-d period). Participants received 1 point if they consumed ≥ 1/4 serving/d of the foods within each subgroup (alone or in combination) and 0 points if they consumed < 1/4 serving/d. For each food group, points were summed across the subgroups and divided by the total number of subgroups and then multiplied by 2.5 to receive a top score of 2.5 points per food group,

TABLE 1
Distribution of scores for the total Diet Quality Index Revised (DQI-R) and for individual index components as estimated by two food-frequency questionnaires (FFQs) and the mean of two 1-wk diet records and the Pearson reproducibility and validity correlations among 127 male health professionals[1]

		Distribution of scores			Correlation (*r*) between FFQ-1 and FFQ-2	Correlation (*r*) between FFQ-2 and diet record
	Scoring criteria	FFQ-1	FFQ-2	Diet record		
Total DQI-R	0–100	40–94	28–92	33–94	0.72	0.72[2]
Index component and recommendation						
1: Total fat, ≤ 30% of energy intake	≤ 30% = 10,	61 (48)[3]	55 (43)	29 (23)	0.46	0.45
	> 30% and ≤ 40% = 5,	57 (45)	61 (48)	85 (67)		
	> 40% = 0	9 (7)	11 (9)	13 (10)		
2: Saturated fat, ≤ 10% of energy intake	≤ 10% = 10,	55 (43)	45 (35)	40 (31)	0.60	0.65
	> 10% and ≤ 13% = 5,	48 (38)	58 (46)	48 (38)		
	> 13% = 0	24 (19)	24 (19)	39 (31)		
3: Dietary cholesterol, < 300 mg/d	≤ 300 = 10,	71 (56)	83 (65)	55 (43)	0.63	0.47
	> 300 and ≤ 400 = 5,	31 (24)	23 (18)	35 (28)		
	> 400 = 0	25 (20)	21 (17)	37 (29)		
4: 2–4 Servings fruit/d, % recommended servings[4]	≥ 100%,	50 (39)	44 (35)	28 (22)	0.72	0.71
	50–99%,	49 (39)	50 (39)	52 (41)		
	< 50%	28 (22)	33 (26)	47 (37)		
5: 3–5 Servings vegetables/d, % recommended servings[4]	≥ 100%,	42 (33)	46 (36)	9 (7)	0.64	0.19
	55–99%,	71 (56)	62 (49)	71 (57)		
	<50%	14 (11)	19 (15)	47 (37)		
6: 6–11 Servings grains/d, % recommended servings[4]	≥ 100%,	1 (1)	1 (1)	4 (3)	0.53	0.39
	50–99%,	30 (24)	28 (22)	51 (40)		
	<50%	96 (67)	98 (77)	72 (57)		
7: Calcium intake, % AI for age[5]	≥ 100%,	25 (20)	24 (19)	18 (14)	0.69	0.54
	50–99%,	82 (66)	83 (66)	95 (75)		
	<50%	20 (15)	20 (15)	14 (11)		
8: Iron intake, % 1989 RDA for age[6]	≥100%,	116 (91)	114 (90)	123 (97)	0.41	0.06
	50–99%,	11 (9)	12 (9)	4 (3)		
	<50%	0 (0)	1 (1)	0 (0)		
9: Dietary diversity	≥ 6,	66 (52)	60 (47)	44 (35)	0.76	0.41
	≥ 3 and <6,	59 (47)	65 (51)	81 (63)		
	< 3	2 (2)	2 (2)	2 (2)		
10: Dietary moderation[7]	≥ 7,	98 (77)	93 (73)	76 (60)	0.68	0.49
	≥ 4 and <7,	28 (22)	33 (26)	50 (39)		
	<4	1 (1)	1 (1)	1 (1)		

[1] From reference 20.
[2] Adjusted for week-to-week variation in dietary intake. The correlation between FFQ-1 and the diet records was 0.66.
[3] *n* (%).
[4] Three servings of fruit, 4 servings of vegetables, and 9 servings of grains are recommended per day for a male consuming 9205 kJ/d (2200 kcal/d) (21).
[5] The adequate intake (AI) is 1000 mg/d for men aged 19–51 y and 1200 mg/d for men aged ≥ 51 y (23).
[6] The 1989 recommended dietary allowance (RDA) for men aged ≥ 19 y is 10 mg/d (23).
[7] The moderation component includes added sugar, discretionary fat, sodium, and alcohol (21) (*see* Table 3).

or 10 points in total for the diversity component across the 4 food groups.

Minor changes were made to the food subgroups because of differences in foods contained on the FFQs used in the Health Professionals Follow-up Study. Notably, whole-grain and non-whole-grain cereals were combined into one subgroup of cereals. We also added an "other grains" subgroup that included wheat germ, bran, and other grains not specified. In addition, the fruit category was expanded from 2 subgroups to 3 subgroups to reflect the large number of "other" fruit contained in our FFQ.

DQI-R dietary moderation component

The dietary moderation component is comprised of 4 subgroups (added sugar, discretionary fat, sodium, and alcohol) that each contribute a maximum score of 2.5 points. The added sugar component is defined by the US Department of Agriculture Food Surveys Research Group (30) and the food guide pyramid (21) to reflect "1 teaspoon of added sugar, where 1 teaspoon is the quantity of a sweetener that contains the same amount of carbohydrate as one teaspoon of table sugar." Products that contribute to added sugar include all sweeteners that are eaten separately or used as ingredients in processed or prepared foods (21). To quantify the added sugar component, we included teaspoons of added sugar consumed per day (eg, added to coffee or cereal), which was directly assessed from the FFQs and diet records. We also derived added sugar intake by summing the sucrose content per serving across major foods, including muffins and biscuits, pancakes and waffles,

nondiet cola, chocolate and nonchocolate candy, cookies, brownies, donuts, cake, pie, sweet roll and coffee cake, and jam, jelly, syrup, and honey. Teaspoons of sugar were derived from the total sucrose intake of the added sugar foods, where 3.8 g sucrose = 1 tsp sugar. Together, the direct and derived sugar values were summed to total added sugar consumption.

Discretionary fat is defined in the food guide pyramid (21) as the difference in fat content between full-fat and low-fat products, specifically, "all excess fat...beyond amounts that would be consumed if only the lowest fat forms were eaten, and fats added to foods in preparation or at the table." To derive discretionary fat intake, we included the fat from foods including cream, butter, margarine, cream cheese, oils, salad dressings, chocolate, whole milk, sour cream, ice cream, mayonnaise, coffee whitener, and baked goods. The grams of fat contained in a serving (29) were then separately calculated (eg, 2 tablespoons cream at 2.9 g fat/tablespoon = 5.8 g discretionary fat) and summed across all foods to derive total discretionary fat consumption. Our method differed slightly from the food guide pyramid definition (21). In this study, we included the absolute number of fat grams contained in these products as discretionary, given that fat-free choices for most of the foods listed above are available and an individual can choose not to consume these foods at all.

Alcohol intake was counted directly for both dietary assessment methods, and sodium (and other nutrient components) was derived by using a nutrient database (29). For sodium, salt used in cooking and at the table was included for both the FFQs and the diet records. Specifically, on the FFQ, the participants were asked how much salt they added to staple foods (eg, rice or pasta), meats, vegetables, and soups during cooking (1/8, 1/4, or 1/5 tsp per serving); the frequency of the foods in the different groups were summed and then multiplied by the salt quantity selected. Participants were also asked on the FFQ to estimate how often they added salt to foods at the table, as well as how many shakes of salt they usually added, where 0.3 g salt was represented in each shake. For diet records, there was a column for participants to directly record both salt added during cooking (in teaspoons) and shakes of salt added to food at the table.

Laboratory analyses

Blood samples were obtained from 121 nonfasting participants shortly before they completed the second FFQ. Blood specimens were collected into EDTA-treated tubes in the morning and then covered with aluminum foil and stored in the dark on ice until the plasma was separated; plasma was stored at −70 °C until analyzed. Plasma carotenoids, tocopherols, and retinol were measured by reversed-phased HPLC in the laboratory of Hoffmann-La Roche (Basel, Switzerland) (31). Plasma cholesterol and triacylglycerol concentrations were measured by using kits from Hoffmann-La Roche, according to the methods of Richmond (32) and Bucolo and David (33), respectively.

Statistical analyses

All analyses were performed by using the SAS statistical software package (version 6; SAS Institute Inc, Cary, NC). For individual DQI-R components, the proportion of men in each scoring category and mean (±SD) intakes were calculated for each dietary assessment method. Mean scores for individual components and the total DQI-R score were also calculated. We calculated Pearson correlation coefficients to assess the reproducibility from the repeated FFQs and the validity comparing the FFQs to the diet records for individual DQI-R components and total DQI-R scores. We calculated deattentuated correlation coefficients to reduce the effect of week-to-week variation in diet record intake, as suggested by Rosner and Willett (34).

Our validation analysis compared total DQI-R scores from the FFQs and diet records with plasma biochemical measurements. Additional validation compared DQI-R scores from both methods with nutrients derived from the diet records. Both analyses used Pearson correlations. Nutrients were energy-adjusted by using the residual method (35) and log-transformed to improve normality. Plasma measurements of retinol, α- and β-carotene, and α-tocopherol were adjusted for age, plasma cholesterol, plasma triacylglycerols, and body mass index. Smokers and users of multivitamin or β-carotene supplements were excluded from retinol and carotenoid analyses, whereas users of multivitamin or single vitamin E supplements were excluded from α-tocopherol analyses.

The distribution of scores for total DQI-R and individual index components and the reproducibility and validity correlations are presented for both FFQ-1 and FFQ-2. All other data are presented for FFQ-2 only because of the similarity of results between the 2 FFQs.

RESULTS

A reproducibility correlation of 0.72 was obtained when the total DQI-R score from FFQ-1 was compared with that from FFQ-2. Reproducibility correlations between the 2 FFQs for individual index components ranged from 0.41 to 0.76, whereas validity correlations ranged from 0.06 to 0.71 (Table 1). The weak validity correlation for iron (r = 0.06) may have been due to limited variation in iron intake, because most subjects met the goal for iron according to both FFQ-2 and the diet records. Intakes of fat, saturated fat, and cholesterol were underreported on the FFQs compared with the diet records. For example, 23% of men met the goal for total fat consumption ($\leq$ 30% of total energy intake) as assessed by the diet records, whereas 43% of men met the goal as assessed by FFQ-2 (r = 0.45). Similarly, 43% of men met the goal for cholesterol consumption ($\leq$ 300 mg/d) as assessed by the diet records, whereas 65% met the goal according to FFQ-2 (r = 0.47).

The validity correlations between each FFQ and the diet records, which were statistically adjusted to reduce the effect of week-to-week variation in diet records, were 0.66 (FFQ-1) and 0.72 (FFQ-2). Validity varied among food group components of the DQI-R. Even though fruit consumption was overreported on the FFQs compared with the diet records, the fruit score was the most highly correlated component between FFQ-2 and the diet records (r = 0.71). A lower correlation was observed for the vegetable score (r = 0.19). Very few men met the goal for grain consumption according to both methods (r = 0.39).

Mean DQI-R scores were 69.5 for FFQ-1, 67.2 for FFQ-2, and 62.0 for the diet records out of a possible 100 points (**Table 2**). Mean scores were higher for the fat, saturated fat, cholesterol, fruit, vegetable, diversity, and moderation components on FFQ-2 than on the diet records. Calcium and iron scores were

TABLE 2
Scores and daily intakes for the total Diet Quality Index Revised (DQI-R) and for individual index components as estimated by food-frequency questionnaire 2 (FFQ-2) and the mean of two 1-wk diet records among 127 male health professionals

	FFQ-2		Diet record	
	Score	Intake/d	Score	Intake/d
Total DQI-R[1]	67.2 ± 14.3[2]	—	62.0 ± 13.8	—
Index component and recommendation				
1: Total fat, ≤ 30% of energy intake	6.7 ± 3.2	31.4 ± 6.3% of energy	5.6 ± 2.8	33.0 ± 6.0% of energy
2: Saturated fat, ≤ 10% of energy intake	5.8 ± 3.6	10.9 ± 2.8% of energy	5.0 ± 4.0	11.3 ± 2.9% of energy
3: Dietary cholesterol, < 300 mg/d	7.4 ± 3.8	287 ± 128 mg	5.7 ± 4.2	342 ± 132 mg
4: 2–4 Servings fruit/d[3]	7.1 ± 2.8	2.8 ± 1.9 servings	6.0 ± 2.9	2.2 ± 1.5 servings
(% recommended servings)	—	93 ± 62%	—	74 ± 48%
5: 3–5 Servings vegetables/d[3]	7.5 ± 2.4	3.7 ± 1.6 servings	5.3 ± 2.2	2.4 ± 1.1 servings
(% recommended servings)	—	91 ± 41%	—	60 ± 29%
6: 6–11 Servings grains/d[3]	3.5 ± 1.9	3.6 ± 1.7 servings	4.5 ± 1.9	4.5 ± 1.8 servings
(% recommended servings)	—	40 ± 19%	—	50 ± 20%
7: Calcium intake[4]	6.9 ± 2.2	804 ± 311 mg	6.9 ± 2.1	796 ± 269 mg
(% AI)	—	75 ± 31%	—	74 ± 27%
8: Iron intake[5]	9.7 ± 1.0	14 ± 5 mg	10.0 ± 0.3	18 ± 5 mg
(% RDA)	—	142 ± 45%	—	180 ± 54%
9: Dietary diversity	6.0 ± 1.3	—	5.6 ± 1.2	—
10: Dietary moderation[6]	8.1 ± 1.7	—	7.3 ± 1.5	—

[1] Total DQI-R score is out of a highest possible score of 100; individual component scores range from 0 to 10.
[2] $\bar{x}$ ± SD.
[3] Values are presented as mean servings and as the percentage of recommended servings. Food guide pyramid (21) recommendations are 3 servings of fruit, 4 servings of vegetables, and 9 servings of grains for a 9205-kJ/d diet.
[4] Values are presented as mean intake and as a percentage of the adequate intake (AI) (23). The AI is 1000 mg/d for men aged 19–51 y and 1200 mg/d for men aged ≥ 51 y.
[5] Values are presented as mean intake and as a percentage of the recommended dietary allowance (RDA) (23). The 1989 RDA for men aged ≥ 19 y is 10 mg/d.
[6] The moderation component includes added sugar, discretionary fat, sodium, and alcohol (21) (*see* Table 3).

similar, although the mean intake of iron was almost 4 mg/d higher on the diet records.

The distribution of scores and mean values for the 4 moderation subgroups of DQI-R component 10 are presented in **Table 3**. Most of the subjects met the goal for sugar consumption according to both FFQ-2 (90%) and the diet records (94%) ($r = 0.21$), whereas almost 3 times as many subjects met the goal for discretionary fat as estimated by FFQ-2 (43%) compared with the diet record (16%) ($r = 0.50$). Alcohol intake was strongly correlated between assessment methods ($r = 0.65$) (correlations not shown).

Presented in **Table 4** are the correlation coefficients and P values comparing DQI-R scores from FFQ-2 and the diet records with plasma biochemical measurements and nutrients from the diet records. DQI-R scores from both methods were directly correlated with plasma biochemical measurements of α-carotene, β-carotene, lutein, and α-tocopherol, but inversely correlated with cholesterol ($P < 0.05$). DQI-R scores calculated from both diet assessment methods were also directly related to vitamins B-6 and C, fiber, folate, magnesium, calcium, and carotene intakes and inversely related to fat, saturated fat, monounsaturated fat, and cholesterol intakes from the diet records ($P < 0.05$).

DISCUSSION

As part of a research effort to examine the utility of dietary patterns (28) and diet indexes (36) in nutritional epidemiologic research, we found in this study that the DQI-R instrument assesses diet quality from an FFQ with reasonable reproducibility over time and with reasonable validity compared with plasma biochemical measurements. Total DQI-R scores were correlated with biomarkers in the expected direction and were of a similar magnitude for FFQ-2 and the diet records. Total cholesterol was inversely related to DQI-R score, an association rarely seen in epidemiologic studies. A significant correlation between DQI-R score and serum cholesterol as measured by FFQ-2 ($r = -0.22$, $P < 0.05$) but not the diet records ($r = -0.15$, $P > 0.05$) may reflect a stronger effect of long-term, usual diet on plasma cholesterol, as measured by the FFQ, as opposed to 2 wk of dietary intake.

We also compared the DQI-R scores from the FFQs and diet records with nutrient intakes estimated by the diet records because diet records have the fewest correlated errors with FFQs and are therefore the most widely used dietary assessment method for validating an FFQ. The major sources of error associated with FFQs are limited food items, memory of food consumed, assessment of portion size, and interpretation of questions. These sources of error are minimally shared with the diet record method, which is open-ended, involves recording of foods as they are consumed, and involves direct weighing of food portions (37). Diet quality assessed from the FFQ showed reasonable validity when compared with nutrient intakes from diet records. Our findings were generally as expected, given that many of the nutrients were specifically incorporated into the DQI-R. However, several nutrients significantly related to the total DQI-R score were not measured by the diet records

TABLE 3
Elements of dietary moderation (component 10) of the Diet Quality Index Revised: distribution of scores and daily intakes as estimated by food-frequency questionnaire 2 (FFQ-2) and the mean of two 1-wk diet records among 127 male health professionals

Moderation component and scoring criteria/d	Score	FFQ-2		Diet record	
		Distribution	Intake/d	Distribution	Intake/d
Added sugar (tsp)[1]					
≤ 100% of maximum	2.5	114 (90)[2]	4.3 ± 2.7[3]	119 (94)	4.8 ± 2.9
> 100% and ≤ 150%	1.5	10 (8)	15.0 ± 1.6	6 (5)	13.2 ± 1.0
> 150% and ≤ 200%	1.0	1 (1)	20.3	2 (1)	18.2 ± 0.1
> 200%	0	2 (1)	24.8 ± 1.0	0	—
Discretionary fat (g)					
≤ 25 g	2.5	54 (43)	17.3 ± 4.8	20 (16)	17.8 ± 6.0
> 25 and ≤ 50 g	1.5	64 (50)	35.2 ± 6.4	72 (57)	37.5 ± 7.3
> 50 and ≤ 75 g	1.0	8 (6)	58.8 ± 7.4	31 (24)	56.7 ± 5.4
> 75 g	0	1 (1)	87.3	4 (3)	86.8 ± 6.2
Sodium (mg)					
≤ 2400 mg	2.5	61 (48)	1757 ± 420	28 (22)	2030 ± 289
> 2400 and ≤ 3400 mg	1.5	37 (29)	2787 ± 274	57 (45)	2825 ± 267
> 3400 mg	0	29 (23)	4472 ± 1290	42 (33)	4417 ± 1428
Alcohol (drinks)[4]					
≤ 100% of maximum	2.5	105 (83)	0.5 ± 0.5	99 (78)	0.6 ± 0.5
> 100% and ≤150%	1.5	10 (8)	2.5 ± 0.2	15 (12)	2.5 ± 0.3
> 150% and ≤200%	1.0	7 (6)	3.4 ± 0.3	8 (6)	3.5 ± 0.2
> 200%	0	5 (4)	4.6 ± 0.4	5 (4)	4.2 ± 0.2

[1] Twelve teaspoons of sugar is the maximum recommended for a 9205-kJ/d diet (21). There are 3.8 g sucrose in 1 teaspoon sugar.
[2] *n* (%).
[3] $\bar{x}$ ± SD.
[4] Two drinks/d or less are recommended for men aged ≥ 21 y (21).

(eg, fiber, vitamin C, and folate), suggesting that the DQI-R captures additional aspects of diet quality.

Several diet quality indexes have been associated with plasma biomarkers and specific nutrient intakes. A diet quality index similar to the DQI-R was positively correlated with plasma concentrations of eicosapentaenoic acid and docosahexaenoic acid and inversely related to cholesterol in a representative sample in southern France (38), whereas an earlier dietary scoring method based on the (then) basic 4 food groups (1) was positively correlated with intakes of calcium and magnesium. More recently, Hann et al (39) observed associations between the Healthy Eating Index and plasma α-carotene ($r = 0.40$, $P < 0.05$) and β-carotene ($r = 0.28$, $P < 0.05$) that were of a similar magnitude to those obtained in our study.

In our study, the correlations between DQI-R scores calculated from both methods and the plasma biomarkers were similar for many of the nutrients, indicating that the FFQ is a reasonable estimate of diet quality when compared with 2 wk of diet records. In general, although FFQs are not as reliable in assessing absolute intakes as are diet records, the reasonable correlations observed indicate that individuals can be ranked with sufficient accuracy with respect to diet quality, as has been shown for intakes of nutrients (26) and foods (27). The underreporting of dietary components perceived as relatively less healthy (eg, saturated fat) and the overreporting of dietary components perceived as relatively more healthy (eg, fruit) on the FFQ contribute to the higher total DQI-R scores seen on the FFQs than on the diet records. These biases of FFQs compared with diet records have been previously discussed (26, 27). Assessment of diet quality, then, must consider the limitations of the primary dietary assessment method when interpreting results generated from different methods.

A limitation of our study was our ability to exactly reproduce the method used in the DQI-R, specifically for discretionary fat and added sugar. Because our FFQ and diet records did not contain direct measures of discretionary fat or added sugar, these components were derived from relevant foods for both methods and our choices of foods to include was instructed by the definitions used in the food guide pyramid (21). It is arguable that additional fat-containing foods should have been counted as discretionary, such as fried foods, which could be baked or broiled rather than fried, or high-fat cuts of meat, which could be replaced by low-fat cuts of meat. A similar problem was encountered for the added sugar component, in which we created a list of foods containing added sugars; additional foods could also have been included, such as sweetened juice drinks or dairy desserts. Omission of these foods with discretionary fat (ie, fried foods or high-fat cuts of meat) or added sugar (ie, sweetened juice drinks or dairy desserts) would, if many participants consumed them in large amounts, lead to a lower score on the moderation component and an overall lower DQI-R score than reported here.

Counting food ingredients from mixed dishes always poses a challenge when assessing dietary intake, and a limitation of this study is the potential loss of dietary information from mixed dishes. For example, a consistent loss of flour from mixed dishes would lead to an underestimation of grain consumption. This may have contributed to the low mean grain consumption observed in our study, thus artificially decreasing the DQI-R score. Another possible reason for our low grain

TABLE 4
Pearson correlation coefficients measuring the association of the total Diet Quality Index Revised (DQI-R) score calculated from food-frequency questionnaire 2 (FFQ-2) and the mean of two 1-wk diet records with plasma biochemical measurements and nutrients from diet records

		Correlations with DQI-R (r)		
	Value	FFQ-2	Diet record	P[1]
Biochemical measurements[2]				
Total cholesterol, n = 121 (mmol/L)	5.13 ± 1.41[3]	−0.22	−0.15	< 0.05 (FFQ-2 only)
Triacylglycerols, n = 121 (mmol/L)	0.93 ± 3.02	−0.04	−0.06	NS
Retinol, n = 92 (μmol/L)[4]	4.10 ± 0.17	0.09	0.15	NS
α-Carotene, n = 91 μmol/L[4]	1.52 ± 0.75	0.43	0.44	<0.0005
β-Carotene, n = 92 (μmol/L)[4]	2.98 ± 0.61	0.35	0.42	<0.005
Lycopene, n = 92 (μmol/L)[4]	3.67 ± 0.41	0.17	0.23	< 0.05 (Diet record only)
Lutein, n = 92 (μmol/L)[4]	2.70 ± 0.38	0.31	0.39	<0.005
α-Tocopherol, n = 95 (μmol/L)[5]	0.10 ± 0.24	0.25	0.28	<0.05
Nutrients from diet records (n = 127)[6]				
Total energy (kJ)	9,067 ± 1,933	−0.08	−0.01	NS
Total fat (g)	79.8 ± 25.3	−0.55	−0.82	<0.0005
Saturated fat (g)	27.5 ± 10.7	−0.57	−0.85	<0.0005
Polyunsaturated fat (g)	16.4 ± 5.1	−0.01	−0.11	NS
Monounsaturated fat (g)	29.0 ± 9.8	−0.56	−0.76	<0.0005
Fiber (g)	19.2 ± 8.1	0.57	0.76	<0.0005
Cholesterol (mg)	342 ± 132	−0.47	−0.69	<0.0005
Calcium (mg)	796 ± 268	0.35	0.26	<0.005
Sodium (mg)	3176 ± 1255	−0.13	−0.14	NS
Vitamin A (IU)	9246 ± 7383	0.22	0.37	<0.05
Carotene (IU)	7179 ± 7178	0.26	0.47	<0.005
Vitamin B-6 (mg)	2.3 ± 0.8	0.49	0.57	<0.0005
Vitamin C (mg)	138.5 ± 65.7	0.59	0.68	<0.0005
Vitamin E (mg)	15.0 ± 5.92	0.16	0.15	NS
Folate (g)	324.7 ± 126	0.50	0.59	<0.0005
Magnesium (mg)	357.4 ± 111	0.56	0.63	<0.0005
Iron (mg)	17.6 ± 4.2	0.36	0.36	<0.0005

[1] P values are for both FFQ-2 and diet records unless otherwise noted.
[2] Retinol, α-carotene, β-carotene, and α-tocopherol were adjusted for age, plasma cholesterol, plasma triacylglycerols, and BMI.
[3] $\bar{x}$ ± SD.
[4] Smokers and users of multivitamin or single β-carotene supplements were excluded.
[5] Users of multivitamin or single vitamin E supplements were excluded.
[6] All nutrients were calculated from average food intakes from two 1-wk diet records and were adjusted for total energy by using the nutrient residual model. Supplementary intakes were not included.

score could be because, in replicating the method of Haines et al (20), we did not count grains consumed from baked goods in our estimate. This method differs from the food guide pyramid (21), which does count these foods toward grain consumption. Therefore, the decision to omit grains from baked goods from the DQI-R score reflects the authors' preferences (20) and not current nutrition policy.

An additional limitation of this study is the homogeneity of our study population, all of whom were highly educated white males. Diet quality varies among populations, and validity of the DQI-R method may vary for women, who generally have healthier diets (20), and for groups of a lower socioeconomic status, who generally have less healthy diets (39).

Assessment of reproducibility and validity of an instrument such as the DQI-R is only one step in the evaluation of a dietary assessment method. Whether the index or other measures of diet quality can predict disease across diverse populations is the ultimate test of validity. A review of diet quality indexes found that diet quality was related to the risk of disease more strongly than were individual nutrients or foods (40), but recent studies examining the relation have led to inconsistent results (3, 12, 36, 41). The inconsistencies could be attributable to specific components included in the indexes that may not be clearly associated with disease risk. For the DQI-R, consuming ≤ 30% of total energy from fat is one of the components, but total fat intake may not be associated with either coronary heart disease (42) or cancer (43), although there is considerable controversy in this area (19, 44). In addition, whole grains may be protective against coronary heart disease, whereas refined grains may increase risk (45), although the DQI-R recommendation for grain consumption, as based on the food guide pyramid (21), does not distinguish between whole and refined grains. As such, diet quality indexes based on current nutrition policy may be limited in utility if nutrition policy itself does not reflect current nutrition knowledge. In addition, an index that is based on current policy may become outdated as nutrition science evolves. Diet quality indexes, then, are only as good as the components on which they are based; hence, they inevitably must be revised if they are truly to reflect the latest nutrition science and policy.

In conclusion, although our findings of reasonable reliability and validity of the DQI-R are positive, they do not necessarily

mean that this index is useful in predicting disease outcomes among persons who conform to the recommendations. Studying whether the DQI-R can reliably predict disease risk is the next step in the validation of its utility as a dietary assessment method.

The study design of the Health Professionals Follow-up Study and validation study was originally conceived by WCW and colleagues at Harvard School of Public Health and Channing Laboratory. WCW, DF, EBR, and LS were responsible for original data collection and data analysis, including the derivation of nutrients (LS). PKN, FBH, and SAS-W were responsible for the study design and data analysis of this study, with specific attention to the coding of the DQI-R and all analyses herein. PKN was the primary analyst and writer of the manuscript. All authors made critical comments during the preparation of the manuscript and fully accept responsibility for the work. No authors had a financial interest or professional or personal affiliations that compromise the scientific integrity of this work.

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APPENDIX A

Elements of the dietary diversity score (component 9) of the Diet Quality Index Revised

Food group	Representative foods
Grains	
Non-whole-grain breads	White bread, pita, bagels, and rolls
Quick breads	Muffins and biscuits
Pasta	Pasta
Whole-grain breads	Dark bread, pizza, and crackers
Cereals	Oatmeal, other cooked cereal, cold breakfast cereal
Rice	Brown or white rice
Other grains	Bran, wheat germ, and other grains
Vegetables	
Deep yellow or orange	Carrots, winter squash, and yams
Deep green	Spinach, broccoli, and kale or chard
Tomato products	Fresh tomatoes, tomato juice, and tomato sauce
Potatoes	Fried or baked potatoes
Dry beans	Beans and lentils and tofu and soybeans
Starchy	Corn, peas, and lima beans
Other	Alfalfa sprouts, celery, string beans, lettuce, green pepper, mixed vegetables, sauerkraut, coleslaw and cabbage, cooked cabbage, cauliflower, Brussels sprouts, and zucchini
Fruit	
Citrus, berries, and melons	Cantaloupe, watermelon, strawberries, blueberries, orange, and grapefruit
Juices	Orange, grapefruit, and other
Other	Raisins and grapes, avocados, bananas, apples and pears, and peaches, apricots, and plums
Meat and dairy	
Beef, pork, organ meats, and lunchmeats	Processed meats, hamburger, hot dog, and beef, pork, and lamb
Poultry	Chicken and turkey
Milk	Whole or low-fat milk and sherbet and ice milk
Cheese	Cottage cheese, ricotta cheese, and other cheese
Eggs and soup	Eggs and soup
Fish	Canned tuna, dark-meat fish, shrimp and lobster, and other fish
Yogurt	Yogurt