Validation of a dietary pattern approach for evaluating nutritional risk: The Framingham Nutrition Studies

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ABSTRACT

Objective To validate the use of cluster analysis for characterizing population dietary patterns.
Design Cluster analysis was applied to a food frequency questionnaire to define dietary patterns. Independent estimates of nutrient intake were derived from 3-day food records. Heart disease risk factors were assessed using standardized protocols in a clinic setting.
Setting Adult women (n=1,828) participating in the Framingham Offspring-Spouse study.
Statistical analyses Age-adjusted mean nutrient intakes were determined for each cluster. Analysis of covariance was used to evaluate pairwise differences in intake across clusters. Compliance with published recommendations was determined for selected heart disease risk factors. Differences in age-adjusted compliance across clusters were evaluated using logistic regression.
Results Cluster analysis identified 5 distinct dietary patterns characterized by unique food behaviors and significantly different nutrient intake profiles. Patterns rich in fruits, vegetables, grains, low-fat dairy, and lean protein foods resulted in higher nutrient density. Patterns rich in fatty foods, added fats, desserts, and sweets were less nutrient-dense. Women who consumed an Empty Calorie pattern were less likely to achieve compliance with clinical risk factor guidelines in contrast to most other groups of women.
Conclusions Cluster analysis is a valid tool for evaluating nutrition risk by considering overall patterns and food behaviors. This is important because dietary patterns appear to be linked with other health-related behaviors that confer risk for chronic disease. Therefore, insight into dietary behaviors of distinct clusters within a population can help to design intervention strategies for prevention and management of chronic health conditions including obesity and cardiovascular disease. *J Am Diet Assoc. 2001;101:187-194.*

Dietary behavior has been associated with the prevention of 6 of the nation's 10 leading causes of death and disability, including coronary heart disease, hypertension, diabetes, osteoporosis, renal disease, and certain cancers (1). Consequently, population-based guidelines for recommended levels of total and saturated fat, fiber, and micronutrients such as B vitamins, beta-carotene, calcium, and sodium intake have been established by various professional groups (2-6). To the same end, national health policies through the year 2010 have highlighted specific nutrition guidelines for various age groups in the US population. As well, current recommendations for health promotion incorporate food-based messages that emphasize the importance of an overall dietary pattern that is rich in fruits, vegetables, grains, and low-fat dairy while lower in food sources of saturated fats and sweets (4).

Further progress in developing informed national nutrition policies and designing effective intervention strategies to promote optimal food and nutrient intake is imperative. Essential to this is the ability to characterize eating behaviors that are associated with both beneficial and detrimental nutrient intakes and health outcomes. The multiple patterns of food consumption in this country (7-13) and others (14-18) suggest

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Table 1
Clusters of women and the food groupings that define them[a] (N=1,828)

Eating pattern	Higher consumption food groupings	Lower consumption food groupings
Heart healthy (n=366)	Vegetables[b], fruits and low-fat milk[c], other low-fat foods[d], legumes, soups, and miscellaneous foods[e]	Diet beverages and vegetable fats[f]
Light eating (n=872)	None[g]	Legumes, soups, and miscellaneous foods[e], refined grains and margarine[h], sweets and other fats[i]
Wine and moderate eating (n=64)	High-fat dairy and snack foods[j], wine and cholesterol-rich foods[k]	Sweetened beverages[l], desserts[m]
High fat (n=370)	Refined grains and margarine[h], diet beverages and vegetable fats[f], sweets and other fats[i]	Fruits and low-fat milk[c], other low-fat foods,[d] high-fat dairy and snack foods[j]
Empty calorie (n=156)	Sweetened beverages[k], desserts[m]	Vegetables[b], wine and cholesterol-rich foods[k]

[a]Levels of consumption did not differ significantly for the red meats and fattier poultry and beer food groupings (7).
[b]The vegetables grouping included vitamin A- and C-rich vegetables, and high-fiber and other vegetables.
[c]The fruits and low-fat milk grouping included vitamin C-rich fruits, high-fiber and other fruits, low-fat dairy beverages, and liquor.
[d]The other low-fat foods grouping included nonfat milk, low-fat yogurt and cheese, poultry without skin, fish, whole grains, low-fat vegetarian products, and diet and decaffeinated beverages.
[e]The legumes, soups, and miscellaneous foods grouping included soups, shellfish, legumes, and higher-fat vegetarian products.
[f]The diet beverages and vegetable fats grouping included diet, caffeinated beverages and firm vegetable fats.
[g]Women in the Light Eating cluster did not consume any food grouping at levels significantly higher than other clusters.
[h]The refined grains and margarine grouping included refined breads and grains and soft vegetable fats and oils.
[i]The sweets and other fats grouping included low-fat sweets and sugars, whole milk, and animal fats.
[j]The high-fat dairy and snack foods grouping included higher-fat yogurt and cheese and salty snack foods.
[k]The wine and cholesterol-rich foods grouping included wine, eggs, and organ meats.
[l]The sweetened beverages grouping included sweet caffeinated beverages and sweet decaffeinated beverages.
[m]The desserts grouping included high-fat desserts, lower-fat desserts, and chocolates.

that population-specific variations in dietary patterns be considered during policy development, nutrition education, and epidemiologic research initiatives.

Despite this recognition, the conventional approach in nutrition epidemiology and research has not emphasized defining distinct patterns of dietary behavior within a population that may influence nutrient intake, disease risk, or health status. In general, the complexities of combined nutrient effects within the context of the total diet have not been fully examined. Nor has the potential confounding of individual nutrient effects by other nutrients found in the diet been adequately considered.

Practitioners and researchers have urged the development of new methods for assessing and interpreting eating behaviors and dietary patterns among populations and subgroups of interest (19) and to examine such patterns in relationship to morbidity and mortality (20). This broadening in scope has resulted in various attempts to characterize the total diet by considering food choices and food combinations, overall dietary quality, and specific dietary behaviors that contribute to the multidimensional exposure we call "diet." It is expected that an analytical strategy that considers the complexity of dietary patterns may be useful for studying diet–disease relationships by addressing issues of collinearity of nutrient intake, nutrient interactions, and confounding.

In this article, we validate a technique for identifying dietary patterns using cluster analysis. This method can be used to compare relationships among patterns of food consumption, nutrient intake, and health risk profiles. Innovative strategies such as this one will inform the development of targeted dietary interventions and enable researchers to consider both the potential beneficial and untoward effects of a combined pattern of dietary intake.

METHODS

The Framingham Study was initiated in 1948 as a longitudinal, population-based study of cardiovascular disease. More recently, other chronic diseases have been studied as outcomes of interest. The original Framingham cohort consisted of 5,209 men and women, aged 28 to 62 years, who represented a two-thirds random sample of the residents of the town of Framingham, Mass. In 1971, some 5,124 Framingham Study offspring and their spouses, aged 12 to 60 years, were recruited to participate in the Framingham Offspring-Spouse (FOS) study (21). Members of the FOS cohort are examined in the Framingham Study clinic every 4 years where they participate in a standardized protocol involving a complete physical examination, laboratory tests, non-invasive diagnostic testing, and updating of medical histories and other pertinent information. At certain exams, detailed dietary data are collected as part of the ongoing Framingham Nutrition Studies.

The data reported here were collected among women at Exam 3 of the FOS cohort during 1984 through 1988. This was the first extensive dietary data collection involving members of this cohort. Some 1,956 women participated in FOS Exam 3, representing 83% of eligible participants. Dietary patterns were characterized using cluster analysis as applied to food consumption data. Of these, 1,828 (93%) completed the Framingham food frequency questionnaire (FFQ) (22). Details of the cluster analysis methodology were previously published (7). In brief, the 145 food items on the FFQ were classified into 42 categories, based on similarities in nutrient content (eg, vitamin A-rich vegetables, medium-fat meats, etc). Next, the 42 food categories were clustered using stan-

Table 2
Age-adjusted dietary profiles of clusters of women (N=1,265)[a]

Nutrient	Eating pattern[b]				
	Heart healthy (n=267)	**Light eating (n=618)**	**Wine and moderate eating (n=40)**	**High fat (n=247)**	**Empty calorie (n=93)**
	LS mean (95% CI)				
Selected macronutrients					
Energy (kcal)	1,604 (1,548-1,661)^{w}	***1,515 (1,478-1,552)***^{x}	1,618 (1,473-1,763)^{w,x}	1,609 (1,551-1,668)^{w}	**1,621 (1,526-1,716)**^{w}
Protein (%)	**17.9 (17.4-18.4)**^{x}	17.7 (17.3-18.0)^{x}	17.8 (16.4-19.1)^{w,x}	16.5 (15.9-17.0)^{w}	***16.4 (15.6-17.3)***^{w}
Monounsaturated fat (%)	***12.3 (12.0-12.7)***^{x}	13.4 (13.1-13.6)^{w}	13.4 (12.5-14.3)^{w}	13.7 (13.3-14.1)^{w}	**13.9 (13.4-14.5)**^{w}
Polyunsaturated fat (%)	7.86 (7.52-8.19)	7.88 (7.66-8.10)	7.64 (6.78-8.51)	7.55 (7.20-7.9)	7.73 (7.16-8.29)
Risk nutrients					
Total fat (%)	***34.5 (33.7-35.3)***^{x}	36.9 (36.4-37.5)^{w}	35.7 (33.5-37.8)^{w,x}	37.8 (36.9-38.7)^{w}	**37.9 (36.5-39.3)**^{w}
Saturated fat (%)	***11.5 (11.1-11.9)***^{y}	12.8 (12.5-13.0)^{x}	11.7 (10.8-12.7)^{y}	**13.7 (13.3-14.1)**^{w}	13.3 (12.7-13.9)^{w,x}
Alcohol (%)	2.70 (2.13-3.27)^{w,x}	3.24 (2.87-3.61)^{x}	**10.4 (8.94-11.86)**^{y}	2.00 (1.42-2.59)^{w,z}	***1.45 (0.49-2.40)***^{z}
Alcohol (drinks)[c]	0.49 (0.39-0.59)^{x}	0.54 (0.48-0.61)^{x}	**1.74 (1.49-2.00)**^{y}	0.34 (0.24-0.45)^{w}	***0.29 (0.12-0.45)***^{w}
Cholesterol (mg/1,000 kcal)	***138.7 (130.9-146.5)***^{x}	153.6 (148.5-158.7)^{w}	**165.0 (144.9-185.0)**^{w}	147.6 (139.5-155.6)^{w,x}	145.3 (132.2-158.5)^{w,x}
Sodium (mg/1,000 kcal)	1,632 (1,582-1,683)	1,618 (1,585-1,652)	1,586 (1,455-1,716)	1,568 (1,515-1,620)	1,630 (1,545-1,716)
Protective nutrients					
Carbohydrate (%)	**47.0 (46.0-48.0)**^{y}	43.7 (43.0-44.4)^{x}	***37.6 (35.1-40.2)***^{z}	45.3 (44.2-46.3)^{w}	45.5 (43.8-47.2)^{w,y}
Fiber (gm/1,000 kcal)	**9.9 (9.5-10.2)**^{y}	8.4 (8.1-8.6)^{x}	8.1 (7.1-9.1)^{w,x}	7.9 (7.5-8.3)^{w}	***7.3 (6.6-7.9)***^{w}
Calcium (mg/1,000 kcal)	**427.8 (410.9-444.8)**^{x}	393.2 (382.1-404.3)^{w}	***339.2 (295.6-382.8)***^{y}	395.0 (377.4-412.5)^{w}	359.0 (330.3-387.6)^{y}
Selenium (μg/1,000 kcal)	66.6 (64.3-69.0)^{x}	65.7 (64.1-67.2)^{x}	**67.4 (61.3-73.5)**^{x}	***60.6 (58.1-63.0)***^{w}	62.0 (58.0-66.0)^{w,x}
Vitamin C (mg/1,000 kcal)	**76.7 (71.8-81.7)**^{y}	60.6 (57.3-63.8)^{x}	61.5 (48.7-74.3)^{w,x}	54.4 (49.3-59.6)^{w}	***50.5 (42.0-58.9)***^{w}
Vitamin B-6 (mg/1,000 kcal)	**1.01 (0.97-1.05)**^{x}	0.92 (0.89-0.95)^{w}	0.94 (0.84-1.05)^{w,x,y}	0.88 (0.84-0.92)^{w,y}	***0.82 (0.76-0.89)***^{y}
Vitamin B-12 (μg/1,000 kcal)	3.77 (3.07-4.47)	4.01 (3.55-4.47)	5.66 (3.87-7.46)	3.24 (2.52-3.96)	3.26 (2.08-4.44)
Folate (μg/1,000 kcal)	**167.7 (159.4-176.1)**^{y}	146.2 (140.7-151.7)^{x}	143.2 (121.7-164.7)^{w,x}	135.7 (127.1-144.3)^{w}	***123.0 (108.9-137.2)***^{w}
Vitamin E (mg/1,000 kcal)[d]	**5.51 (5.26-5.77)**^{x}	4.93 (4.77-5.10)^{w}	4.81 (4.15-5.46)^{w}	4.82 (4.55-5.08)^{w}	***4.51 (4.08-4.94)***^{w}
Beta-carotene (μg/1,000 kcal)	**2,429 (2,134-2,723)**^{x}	2,206 (2,013-2,398)^{x}	2,115 (1,358-2,872)^{w,x}	1,775 (1,470-2,080)^{w}	***1,594 (1,096-2,091)***^{w}

[a]Of the 1,828 women who completed the FFQ for cluster analysis, 1,265 provided complete 3-day dietary records for estimation of nutrient intake.
[b]Means that are italicized and boldfaced are significantly lowest; means that are boldfaced are significantly highest; means with different superscripts are significantly different from each other at $P<.05$. Analysis of covariance (with PDIFF option for pairwise *t* tests) was used to compute least square means and to test for differences in nutrient intake for each pair of clusters (30).
[c]One drink is defined as 1.5 fl oz liquor, 12 fl oz beer, or 5 fl oz wine (4).
[d]Total vitamin E activity (total α-tocopherol equivalents in milligrams).

Table 3
Dietary risk continuum among clusters of women (N=1,265)[a]

	Eating pattern[b]				
	Heart healthy (n=267)	Light eating (n=618)	Wine and moderate eating (n=40)	High fat (n=247)	Empty calorie (n=93)
Overall mean rank of nutrient intake[c]	***561***[y]	644[x]	661[x,z]	662[x,z]	**679**[z]
Overall dietary risk[d]	1	2	3	4	5

[a]Of the 1,828 women who completed the FFQ for cluster analysis, 1,265 provided complete 3-day dietary records for estimation of nutrient intake.
[b]Means that are italicized and boldfaced are significantly lowest; means that are boldfaced are significantly highest; means with the same superscript are not significantly different from each other at $P \geq .05$. Analysis of covariance (with PDIFF options for pairwise *t* tests) was used to compute least square means and to test for differences in overall rank for each pair of clusters (30).
[c]Nutrient intake levels among all women with 3-day dietary records were ranked from 1 to 1,265. Ranks were assigned so that a person with a relatively more desirable intake level (eg, lower fat or higher vitamin or mineral intake) received a lower rank, whereas a person with a less desirable intake level (eg, higher fat or lower micronutrient intake) received a higher rank. An overall mean rank was computed using the mean of the ranks of the 19 individual nutrient variables (listed in Table 2). First, we computed the mean rank across the 19 nutrients for each of the 1,265 women in the cohort. For a given person, this mean of the ranks over the 19 nutrients represented the overall nutrient rank. The age-adjusted least square mean of these overall ranks was then computed for each cluster.
[d]The age-adjusted overall mean ranks were ordered from 1 (most desirable overall rank) to 5 (least desirable overall rank) to provide an indicator of overall dietary risk.

dard statistical methods (VARCLUS in SAS) into 13 food groupings according to similarities in frequency of consumption (number of daily servings reported) within the cohort. This procedure grouped foods according to their usual frequency of consumption, not by consumption at similar times of day, at the same meal, or in similar serving sizes. This resulted in grouping of foods that may or may not be consumed together, but rather with a similar frequency pattern. For example, women who reported a relatively higher frequency of consumption of fruits also reported a higher frequency of consumption of low-fat milk products. Perhaps counter intuitively, these women also reported higher frequency of liquor consumption. Finally, Ward's clustering method (23) was used to separate women into nonoverlapping groups based upon similarities in their consumption of these foods. Five clusters of women were identified through this process, representing 5 distinct dietary patterns within the cohort (Table 1).

In our previous study (7), nutrient intake was estimated using a single 24-hour recall to characterize mean intake levels for each cluster. Here, more representative nutrient estimates (Table 2) are derived from 3-day dietary records collected using a standardized, published methodology (22,24). Participants were instructed by a registered dietitian in the clinic to record their intake over 2 weekdays and 1 weekend day, while adhering to their usual eating practices. Subjects were trained to estimate portion sizes using a validated 2-dimensional food portion visual (24). Dietary records were processed by trained coders who adhered to standardized protocols. Nutrient calculations were performed using the Minnesota Nutrition Data System software (version 2.6, Food Database 6A, Nutrient Database 23, Nutrition Coordinating Center, University of Minnesota, Minneapolis) (25).

Complete 3-day dietary records were provided by 1,265 women, representing approximately 70% of those included in the cluster analysis. Therefore, although the cluster analysis characterized dietary patterns using data from all 1,828 women who completed the FFQ at Exam 3, nutrient estimates and risk factor compliance data shown here are based on the subset of those 1,265 women who also completed the more intensive dietary record protocol. To determine if the use of a smaller sample may have biased these results, we compared women who completed the dietary record protocol to those that did not provide dietary records. On average, those who completed the records were notably older (mean age 48.8 years vs 46.7 years), leaner (mean body mass index (BMI) 25.0 vs 26.2), and more likely to be nonsmokers (75% vs 62%). However, we looked at risk factor compliance among the full cohort of 1,828 and found that relationships across clusters were identical to those presented here on the subset of 1,265 women.

Risk factors for coronary heart disease are routinely measured at all Framingham Study exams. Methods for determining risk factors status within the Framingham Study have been summarized by Cupples et al (26) and are highlighted here. BMI was calculated from height and weight values measured in the Framingham clinic using standardized techniques. All lipid analyses were performed at the Framingham Heart Study laboratory, which participates in the Standardization Program of the Centers for Disease Control and the National Heart, Lung, and Blood Institute Lipid Research Clinics. Venous blood was drawn from all subjects after a 12-to-24-hour fast. Total cholesterol levels were measured by automated enzymatic methods (27,28). The cholesterol content of low-density lipoprotein (LDL) cholesterol was estimated by the method of Friedewald et al (29). Blood pressure was determined by duplicate measurements on the participants' left arm using a mercury sphygmomanometer with the participant in a sitting position. Hypertension was defined as systolic blood pressure ≥140 mm Hg, diastolic blood pressure ≥90 mm Hg, or the use of antihypertensive medication. Cigarette smoking was self-reported.

Analyses

Age-adjusted mean nutrient intake levels were determined for each cluster of women. We used the analysis of covariance procedure (with PDIFF option for pairwise t tests) to compute least square means and to test for statistical differences in nutrient intake for each pair of clusters (30).

For each cluster, age-adjusted proportions of women who met population-based guidelines for selected heart disease risk factors were calculated. Compliance with risk factor guidelines was defined as being normal weight, having desirable blood levels of total and LDL cholesterol, being normotensive,

Table 4
Age-adjusted compliance with current guidelines, by cluster (N=1,265)[a]

	Eating pattern[b]				
	Heart healthy (n=267)	**Light eating (n=618)**	**Wine and moderate eating (n=40)**	**High fat (n=247)**	**Empty calorie (n=93)**
	← mean±standard deviation →				
Age (yrs)	**50.7±10.21**^{x}	48.5±9.98^{y}	48.8±7.04^{x,y}	48.5±10.13^{y}	***46.4±10.52***^{y}
Risk factor compliance	← % →				
Normal weight[c]	56^{x,y}	61^{x}	**65**^{x}	60^{x}	***45***^{y}
Desirable total cholesterol[d]	48^{x}	42^{x}	37^{x}	40^{x}	37^{x}
Desirable LDL-cholesterol[e]	53^{x}	52^{x}	**61**^{x}	46^{x}	***33***^{y}
Normotensive[f]	71^{y}	77^{x}	***66***^{x,y}	**79**^{x}	71^{x,y}
Nonsmoker	**86**^{z}	76^{y}	78^{x,y,z}	64^{x}	***60***^{x}

[a]Of the 1,828 women who completed the FFQ for the cluster analysis, 1,265 who provided complete 3-day dietary records are included in these analyses.
[b]Values that are italicized and boldfaced are significantly lowest; values that are boldfaced are significantly highest; values with the same superscript are not significantly different from each other at $P \geq .05$. Differences in age-adjusted proportions were computed using logistic regression and proportions were compared across clusters using the Wald test via the TEST option (30).
[c]Normal weight defined as BMI 18.5 to 24.9 (31).
[d]Desirable total cholesterol defined as <5.17 mmol/L (<200 mg/dL (32). To convert mmol/L cholesterol to mg/dL, multiply mmol/L by 38.7. To convert mg/dL cholesterol to mmol/L, multiply mg/dL by 0.026 (40).
[e]Desirable LDL-cholesterol defined as <3.36 mmol/L (<130 mg/dL) (32). To convert mmol/L cholesterol to mg/dL, multiply mmol/L by 38.7. To convert mg/dL cholesterol to mmol/L, multiply mg/dL by 0.026 (40).
[f]Normotensive is defined as systolic blood pressure <140 mm Hg, diastolic blood pressure <90 mm Hg, or not on antihypertensive medication.

and being a nonsmoker. Normal weight was defined as BMI between 18.5 and 24.9 (31). Desirable blood total cholesterol was <5.17 mmol/L (to convert mmol/L cholesterol to mg/dL, multiply mmol/L by 38.7. To convert mg/dL cholesterol to mmol/L, multiply mg/dL by 0.026. Cholesterol of 5.17 mmol/L=200.1 mg/dL) and desirable LDL cholesterol was <3.36 mmol/L (32). Normotension was defined as not being hypertensive according to the Framingham Study definition detailed above (26). Differences in age-adjusted proportions of women achieving compliance were computed using logistic regression. Next, proportions were compared across clusters using the Wald test via the TEST option in the logistic procedure (30). We considered adjustment for other potential confounders (smoking, BMI, and physical activity) in these multivariate analyses.

RESULTS

Cluster analysis identified 5 distinct dietary patterns among FOS women. Labels were assigned to the clusters as a means of identifying them with respect to dietary quality as previously assessed in terms of Food Guide Pyramid standards (7). In this cohort, the dietary patterns that were identified were Heart Healthy, Light Eating, Wine and Moderate Eating, High Fat, and Empty Calorie.

Table 1 distinguishes the clusters from one another by highlighting the food groupings that were consumed at significantly higher or significantly lower levels relative to other clusters (P<.05). Of the 13 food groupings derived from the FFQ, 11 were consumed at significantly different levels across clusters of women (7). The remaining 2 food groupings, Red Meats (high-fat and lower-fat meats, and mixed dishes) and fattier poultry and beer, were consumed at similar levels by all groups of women.

The dietary pattern of the Heart Healthy cluster was characterized by higher consumption of foods that are typically recommended for health promotion. The Light Eating cluster was distinguished from the others largely in terms of relatively lower intakes of certain food groupings, because of their overall low food intake. Aside from a relatively higher consumption of wine, women in the Wine and Moderate Eating cluster practiced moderation by consuming fewer servings of hidden fats and sweets. Women in both the High Fat and Empty Calorie clusters ate fewer servings of more healthful, nutrient-dense foods relative to other clusters of women. Whereas women in the High Fat cluster chose more servings of foods richer in fat content and/or with visible fats added, women in the Empty Calorie cluster consumed more fat-laden desserts and sweets.

Dietary Patterns in Relation to Nutrient Intake

We established that the nutrient intake profiles of the clustered women warranted their placement along a continuum of overall dietary risk, and provide 1 level of validation for this method of food behavior assessment as found in Table 2. This was accomplished by ranking the nutrient intake levels for each person in the cohort, computing the mean rank across the 19 nutrients for each women, and then computing the overall age-adjusted mean rank for each cluster (Table 3). This overall mean rank emphasizes the relative differences between the clusters of women in terms of overall dietary risk and the continuum of risk. Further details on the rank-ordering method and its interpretation appear in Table 3.

At one end of the spectrum, it was confirmed that a Heart Healthy pattern was associated with a lower-fat, nutrient-dense intake profile. At the other extreme, a higher fat, less nutrient-dense Empty Calorie eating pattern was established. Within the continuum, dietary patterns ranged from a lower-energy pattern (Light Eating) to a pattern characterized by markedly higher alcohol intake (Wine and Moderate Eating) and finally to a pattern rich in total and saturated fat (High Fat).

In Table 2, nutrients were categorized to differentiate those that are associated with chronic disease risk (risk nutrients) from those that have been suggested to offer protection against chronic disease risk (protective nutrients). Note that monounsaturated fat was grouped with "selected macronutrients" rather than with "protective nutrients" in this table. This was done because the majority of monounsaturated fat consumed by FOS participants was derived from animal products (which also contribute saturated fat) rather than from plant sources such as olive oil (33). This observation is in contrast to a Mediterranean dietary pattern, but is consistent with food consumption patterns of the general US population (33).

The Heart Healthy pattern was characterized by significantly higher intakes of protein and protective nutrients, specifically carbohydrate; fiber; calcium; vitamins C, B-6, and E; folate; and beta-carotene ($P<.05$). These women also had significantly lower intakes of monounsaturated fat and risk nutrients including total fat, saturated fat, and dietary cholesterol ($P<.05$). Those in the Light Eating cluster consumed significantly less total energy relative to other groups of women ($P<.05$). Those in the Wine and Moderate Eating cluster consumed markedly higher amounts of alcohol; more cholesterol and selenium; and less saturated fat, carbohydrate, and calcium than other groups. Whereas women in the other clusters consumed only one-half of an alcoholic beverage or less daily on average, women in the Wine and Moderate Eating cluster drank nearly 2 drinks per day (mean intake of 1.74 drinks, 95% confidence interval=1.49-2.00). The high Fat cluster was characterized by notably higher intakes of total and saturated fat and lower intake levels of selenium and other protective nutrients. Women in the Empty Calorie cluster consumed diets that were low in nutrient quality despite their higher energy content. Their eating pattern was substantially lower in protective vitamins, fiber, protein, and alcohol, and higher in energy, total fat, and monounsaturated fat compared with the other groups.

Dietary Patterns in Relationship to Heart Disease Risk Factors

As a further level of validation for characterizing the dietary patterns of women, we examined compliance with recommendations for selected heart disease risk factors among the clusters. Mean age is also reported to illustrate the notable difference in age across the clusters. Age-adjusted proportions of women who were normal weight, had desirable serum total and LDL cholesterol levels, were normotensive, or were nonsmokers are shown in Table 4. Multivariate analyses that considered potential confounders other than age were examined but results were not different from the age-adjusted data shown here.

Heart Healthy cluster women, on average, were significantly older and most likely to be nonsmokers. Among women in the Light Eating cluster, only half or fewer had desirable lipid levels. Yet, these women were not distinguished by either substantially higher or lower rates of compliance for these risk factors, in general. Women in the Wine and Moderate Eating group were most likely to be normal weight and have desirable LDL cholesterol levels, but were least likely to be normotensive. Thus, although women in the Wine and Moderate Eating group were least likely to be overweight, their prevalence of hypertension was notably higher. In contrast, women in the High Fat cluster were most likely to be normotensive but had relatively lower compliance with LDL cholesterol standards. Finally, those in the Empty Calorie cluster were the youngest and perhaps the most at risk. Overall, they had notably lower levels of compliance with most of these risk factor guidelines. These women were most likely to smoke, to be overweight, and to have undesirable LDL cholesterol levels.

Compliance with total cholesterol guidelines was low overall. Compliance did not differ significantly across clusters, although more women in the Heart Healthy cluster achieved desirable total blood cholesterol levels (48% vs 37% to 42% in other groups). Still, half or more of women in each cluster had elevated total cholesterol levels.

DISCUSSION

This paper provides data on dietary patterns of free-living adult women who participated in the FOS nutrition studies. Our findings confirm the validity of a food-based analytical strategy, such as cluster analysis, for identifying dietary patterns and food behaviors that enable evaluation of nutrition risk. This work involves an innovative use of a FFQ in the context of an analysis that enables characterization of overall dietary patterns. We believe that this approach is directly applicable to the development of nutrition interventions because of its ability to provide insight into food behaviors and multifaceted patterns of food consumption among discrete segments of the population.

It is notable that dietary patterns based upon differences in food consumption were associated with distinct and consistent differences in nutrient intake profiles. Diets that were on the more desirable end of the spectrum included more servings of fruits, vegetables, and low-fat foods, were lower in fat content, and higher in nutrient quality. In contrast, those that contained more servings of sweets and fat-rich foods with fewer servings of fruits and vegetables were higher in fat content, and less nutrient-dense.

A number of studies have demonstrated the existence of multiple dietary patterns within a given cohort (7-18) and a few have established links between dietary patterns and health outcomes (10,11,13,14,16,18,20). In this cohort of Framingham women, dietary patterns were linked with other health-related behaviors and biological factors that confer risk for chronic disease, such as smoking cigarettes or being hypertensive, dyslipidemic, or overweight. A heavier burden of multiple risk factors was noted among women who had an Empty Calorie eating pattern. In contrast, women who followed a Heart Healthy dietary pattern seemed to model other protective behaviors, including being less likely to smoke.

It appears that women in the Heart Healthy cluster were probably those with established and notable risk factors that likely prompted them to adopt more healthful eating habits. Thus, these cross-sectional analyses may not depict the true relationship between improved eating habits and better risk factor profiles. In fact, these women appear to be in transition as they are making positive lifestyle and behavioral changes. Longitudinal analyses that are currently underway should clarify these relationships and the interpretation of risk associated with specific dietary patterns.

Higher consumption of alcohol in the Wine and Moderate Eating group was associated with higher levels of hypertension (33%). The observed higher rate of hypertension in this cluster prompts us to carefully interpret other research that indicates a beneficial effect of alcohol consumption (specifically wine) on heart disease risk (particularly high-density lipoprotein (HDL) cholesterol levels). Our data demonstrate that a dietary pattern characterized by wine drinking in combination with otherwise moderate dietary behaviors appears to be associated with adverse implications for blood pressure. This relationship between alcohol intake and blood pressure is apparent at a level of alcohol consumption that is about twice the level recommended in the dietary guidelines. Women in the Wine and Moderate Eating cluster were consuming, on average, almost 2 alcoholic drinks per day. This is in contrast to the recommendation that women should limit their daily alcohol consumption, if consumed at all, to 1 drink or less.

Although women in the Wine and Moderate Eating group tended to have better compliance with LDL-cholesterol guidelines relative to other women, compliance with total cholesterol guidelines tended to be a bit lower (but not significantly different from other groups of women). A trend toward lower compliance on total blood cholesterol may be related to the significantly higher intake of dietary cholesterol consumed by women in this cluster. It also may be the result of significantly higher HDL-cholesterol levels observed among women in this cluster (data not shown). Their mean total-to-HDL cholesterol ratio was 3.4±0.2 (desirable is ≤4.5 [34]). Nonetheless, the negative consequences of a dietary pattern featuring excessive daily wine consumption on blood pressure and hypertension prevalence need to be considered in conjunction with the positive effect on HDL-cholesterol levels typically associated with alcohol intake.

In Framingham, the most prevalent dietary pattern observed among women was that of the Light Eating group. Almost half of women in our cohort consumed this low-energy dietary pattern. The Light Eating pattern was relatively lower in micronutrient density, yet contributed a fairly substantial proportion of energy from fat (37% of kilocalories on average) and saturated fat (13% of kilocalories on average). The Heart Healthy dietary pattern was consumed by only one-fifth of the women in this cohort. Nonetheless, acknowledgement of the positive aspects of this dietary pattern can serve as a source of encouragement and positive reinforcement to promote maintenance of desirable food behaviors among these women. Furthermore, the Heart Healthy pattern can serve as a model for educating other women not only about ways to control intake of risk nutrients, but also about ways to enhance intake of foods that are rich sources of protective nutrients.

Another 20% of women fell into the High Fat cluster. The Wine and Moderate Eating cluster and the Empty Calorie cluster represented dietary patterns of much smaller proportions of women (3% and 8%, respectively). The nutrition and health implications of these behavior patterns deserve to be recognized and certainly warrant attention. It is the unique features of these dietary patterns, such as higher alcohol consumption and low nutrient density, that characterize and differentiate the eating habits and risk profiles of discrete subgroups of a population. If not carefully considered, they could easily be obscured by traditional analytical approaches that simply examine risk associated with intake levels of a single nutrient.

The validity of the dietary pattern methodology had not been described until very recently. Hu et al (35) were among the first to demonstrate the reproducibility and validity of a dietary pattern analysis using a food frequency questionnaire in a cohort of men (35). Our findings add further support to the validity of this approach. We were able to establish consistency between patterns of dietary behavior (assessed by the FFQ) and nutrient intake profiles determined from an independent method (3-day food records), as well as with biological and behavioral risk factors. Cluster analysis enabled us to distinguish nonoverlapping groups of women who had distinct dietary patterns that were confirmed to be associated with substantially different levels of nutrient intake and selected disease risk factors. Our findings compare favorably with the validations undertaken by other researchers (13,35) but add the dimension of a spectrum of eating patterns that appears related to heart disease risk factors in women.

Insights into dietary behaviors of distinct clusters within a population can help to target health promotion messages and design intervention strategies to address the specific behavioral concerns of the persons whose diets fit that pattern. For example, younger women in this study tended to consume an Empty Calorie dietary pattern that was high in energy and fat content yet low in nutrient density. These women were more likely to be overweight and dyslipidemic and were more likely to smoke. Consideration of the multidimensional aspects of their dietary pattern, as well as other health-related behaviors such as smoking and exercise habits, would facilitate the development of multidisciplinary behavior-change strategies and more targeted health communication messages.

The clinical trial literature has already demonstrated the utility of a dietary pattern approach in designing effective nutrition interventions that significantly improve blood pressure (36,37) and other cardiovascular risk factors (37,38). The Dietary Approaches to Stop Hypertension diet is a particularly relevant example with widespread applicability, because it relies on commonly available foods, including lean meats and low-fat dairy foods, to develop a dietary plan that the general US population could potentially adopt (36). An advantage of our analytical method is that it can inform the design of interventions that consider unique dietary behaviors that exist within the population and enable professionals to target food selection behaviors for modifications that are most acceptable to female consumers in the long term. This approach is similar to the "staged" exercise recommendations that have been found successful in Project Active, a randomized lifestyle physical activity intervention (39).

Together, the scientific evidence supports the importance of translating a focus on dietary patterns into practice to achieve public health results. The outcome may be an acceleration in the movement of the US population toward adopting more healthful eating habits and reducing the occurrence of nutrition-related chronic diseases.

APPLICATIONS

■ The findings of this research have important implications for assessing nutritional risk and for planning health promotion activities for the general public. It is clear that there is no single or universal dietary pattern.

■ We and others (7-18,20) have demonstrated that subgroups of individuals within a variety of populations have dietary patterns that are quite distinct in terms of food behaviors and dietary quality. To be effective as practitioners, we need to recognize this diversity. We must develop tailored health communications and educational and counseling strategies that emphasize dietary patterns that promote health and warn of those that confer risk.

■ This research mandates the need to address the unique dietary and behavioral characteristics of different segments of the population. A focus on the total diet would surely facilitate dietary guidance that is food-focused, practical, relevant, and meaningful to consumers. Attention to unique dietary patterns in a population can also facilitate the identification of targets for population health messages and mass media health and nutrition campaigns.

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