The Journal of Nutrition
Nutritional Epidemiology

See corresponding editorial on page 653.

Variations in Dietary Patterns Defined by the Healthy Eating Index 2015 and Associations with Mortality: Findings from the Dietary Patterns Methods Project

Angela D Liese,[1] Edwina Wambogo,[2] Jennifer L Lerman,[2] Carol J Boushey,[3] Marian L Neuhouser,[4] Song Wang,[5] Brook E Harmon,[6] and Lesley F Tinker[4]

[1]Department of Epidemiology and Biostatistics, Arnold School of Public Health, University of South Carolina, Columbia, SC, USA; [2]Division of Cancer Control and Population Sciences, National Cancer Institute, NIH, US Department of Health and Human Services, Bethesda, MD, USA; [3]Epidemiology Program, University of Hawaii Cancer Center, Honolulu, HI, USA; [4]Cancer Prevention Program, Division of Public Health Sciences, Fred Hutchinson Cancer Research Center, Seattle, WA, USA; [5]Department of Computer Science and Engineering, University of South Carolina, Columbia, SC, USA; and [6]Nutrition and Health Care Management, Appalachian State University, Boone, NC, USA

ABSTRACT

Background: It is currently unknown if within high-quality dietary intake there exist distinct dietary patterns associated with health benefits that are identifiable with multidimensional dietary pattern analyses. The purpose of this study was to identify specific dietary patterns and groups therein and their associations with all-cause, CVD, and cancer mortality.

Methods: We conducted sex-specific k-means cluster analyses within Healthy Eating Index 2015 (HEI-2015) quintile 5 in 3 US cohorts [NIH-American Association of Retired Persons Diet and Health Study (AARP), the Multiethnic Cohort (MEC), Women's Health Initiative Observational Study (WHI OS)], clusters ranging from $n = 1190$ to $n = 12{,}007$. Characterizations incorporated HEI-2015 overall and component-specific percentage adherence goals, using untruncated and truncated radar graphs and shape analyses. Using cohort- and sex-specific Cox proportional hazards models, associations of quintile 5 clusters with all-cause, cardiovascular disease (CVD), and cancer mortality were evaluated relative to quintile 1.

Results: In each cohort sex-specific sample, 3 identified clusters included 16%–62% of participants, providing evidence for variation within high-quality dietary intake. Clusters revealed commonalities in total fruits and whole fruits intakes that exceeded goals and high sodium intake. Dairy and whole grain intakes oftentimes fell below goal. Some clusters were in addition characterized by total vegetables, greens & beans, and seafood & plant protein intakes exceeding goals. All high-quality dietary patterns were associated with a multivariable-adjusted significant 15%–26% lower risk of all-cause death than diet intake in quintile 1 (except for cluster 2 in WHI OS), and with a 16%–25% lower risk of CVD mortality in the AARP and MEC cohorts. Cancer mortality results were inconsistent.

Conclusions: Multiple ways to achieve a high-quality diet were identified and significant associations with lower all-cause and CVD mortality were seen in some cohorts. *J Nutr* 2022;152:796–804.

Keywords: dietary patterns, Healthy Eating Index, all-cause mortality, cardiovascular disease mortality, cancer mortality, adults, cluster analysis, shape analysis, Dietary Patterns Methods Project, cohort

Introduction

One of the key findings of the Dietary Patterns Methods Project (DPMP), a multi-institutional effort to standardize dietary pattern research through consistency of methods, was that 4 diet quality indexes [i.e., Healthy Eating Index (HEI) 2010, Alternative Healthy Eating Index (AHEI) 2010, alternate Mediterranean Diet (aMED), and the Dietary Approaches to Stop Hypertension (DASH) diet] could be used as a basis for future dietary recommendations (1–4). The DPMP found high-quality diets as characterized by intakes in the highest compared with the lowest quintile of these indexes to be significantly and consistently associated with an 11%–28% reduced risk of death due to all causes, cardiovascular disease (CVD), and cancer in 3 large cohorts (4). Since then, the Dietary Guidelines for Americans have been updated (5, 6) and the HEI-2015 developed (7, 8). Therefore, the DPMP has repeated the

Manuscript received August 10, 2021. Initial review completed September 22, 2021. Revision accepted October 28, 2021.
First published online October 11, 2021; doi: https://doi.org/10.1093/jn/nxab383.

standardized analyses in all participating cohorts using the HEI-2015, with findings being extremely similar to those of the HEI-2010 (8–10).

Several questions related to the nature of the high-quality diet remain unanswered. To date, the DPMP has not explored if there are multiple, distinct ways that a high-quality diet can be achieved within the framework of a diet quality index such as the HEI. Moreover, we do not know how these high-quality patterns may differ from one another with respect to their composition (i.e., multidimensionality) (11), advancing our understanding of dietary patterns beyond a total diet score (i.e., single dimension). In addition, multidimensional techniques may allow for detection of covariation in various dietary components beyond what has been done to date, thus proving informative relative to mortality outcomes (4).

Fortunately, there exist analytic and descriptive techniques that can support a multidimensional evaluation (7, 9, 12, 13). Cluster analysis uses Euclidean distance measures to identify groups of people with similar characteristics, i.e., dietary intake, minimizing differences of components within each group while maximizing differences between groups (14). Radar graphs depict a multitude of characteristics simultaneously for individuals or groups, which can then be interpreted visually (15). Shape analysis, often used in medical image processing, converts a shape into quantitative data, allowing for further analysis and comparison (16, 17). These techniques all evaluate the totality of data, in our case dietary intake data, by considering multiple (dietary) components collectively and simultaneously as well as separately (11).

Thus, the purpose of this phase of the DPMP was to conduct a series of standardized analyses, specifically focusing on multidimensional dietary characteristics: *1*) using cluster analysis to identify specific dietary patterns that exist among women and men in 3 large US-based cohort studies consuming a high-quality diet (i.e., in each cohort-specific HEI-2015 quintile *5*); *2*) to evaluate whether these patterns fall into similar groups (to which we will refer as constellations) based on analyses of shape differences; and *3*) to identify potential differences in the associations of cohort- and sex-specific quintile 1 and the quintile *5* constellations with all-cause, CVD, and cancer mortality in all 3 cohorts.

Supported by National Cancer Institute (NCI) contract HHSN261201800769P (to ADL). Support for the Multiethnic Cohort (MEC) comes from NIH/NCI grant 4R37 CA 54281 with additional support from NCI contract HHSN261201200423P and NIH/NCI grant P30 CA071789. The Women's Health Initiative (WHI) program is funded by the National Heart, Lung, and Blood Institute (NHLBI), NIH, US Department of Health and Human Services (DHHS) through contracts 75N92021D00001, 75N92021D00002, 75N92021D00003, 75N92021D00004, 75N92021D00005, HHSN268201600018C, HHSN268201600001C, HHSN268201600002C, HHSN268201600003C, and HHSN268201600004C. Access to data were provided by the Multiethnic Cohort and The Womens Health Initiative.
Author disclosures: The authors report no conflicts of interest.
Address correspondence to ADL (e-mail: liese@sc.edu).
Supplemental Tables 1–7 and Supplemental Figures 1 and 2 are available from the "Supplementary data" link in the online posting of the article and from the same link in the online table of contents at https://academic.oup.com/jn/.
Abbreviations used: AARP, NIH-American Association of Retired Persons Diet and Health Study; CVD, cardiovascular disease; DPMP, Dietary Patterns Methods Project; HEI, Healthy Eating Index; MEC, Multiethnic Cohort; MPED, MyPyramid Equivalents Database; NCI, National Cancer Institute; WHI OS, Women's Health Initiative Observational Study.

Methods

Overview of the DPMP

The DPMP was initiated as a collaboration between 4 research groups, 1 of which, the National Cancer Institute (NCI), provided leadership for the overall project; the 3 other groups included the University of Hawaii Cancer Center, the Fred Hutchinson Cancer Research Center as the Women's Health Initiative Observational Study (WHI OS) Clinical Coordinating Center, and the University of South Carolina (4, 18). Details of DPMP design, collaboration, and study findings have been published elsewhere (1–4).

The cohorts include the NIH-American Association of Retired Persons Diet and Health Study (AARP), the Multiethnic Cohort (MEC), and the WHI OS. All 3 cohorts were initiated in the mid-1990s with ongoing ascertainment of outcomes. For details see **Supplemental Table 1**. Middle-aged and older adults were recruited in all cohorts, with mean ages at baseline in the early 60s. The AARP and MEC include both sexes, whereas the WHI OS was restricted to postmenopausal women. The majority of AARP and WHI OS participants are non-Hispanic white, whereas the MEC was designed to enroll a multiethnic sample. Each cohort is characterized by a sample size ranging from >93,676 (in the WHI OS) to >424,663 (in the AARP).

For the present DPMP work, investigators aimed to *1*) examine the HEI-2015, particularly the cohort-specific top quintile (quintile *5*), as representing a high-quality diet; *2*) apply a uniform process for coding this index and conducting cluster analyses; *3*) adjust for similar covariates in comparable, if not identical manners, using full multivariate models; and *4*) include the same mortality outcomes. Investigators met monthly to discuss all scientific aspects of the project. Statistical analyses were conducted at the NCI. Each team of investigators sought and received approval for this project in accordance with the policies of their respective institution's Institutional Review Board and in accordance with each cohort's publications, presentations, or consortium policies.

Diet assessment methods, HEI-2015 definition, and covariates in the DPMP

In all 3 cohorts, dietary intake was assessed using a comprehensive self-administered FFQ that included dietary intake over the past year in the AARP and MEC and the past 3 mo in the WHI OS. The questionnaires have been described previously (1, 3, 19–24) and can be found at the studies' websites (25–27). Use of nutrient databases varied between cohorts (2, 3). Conversion of reported food and beverage intake amounts into a uniform system of nutritionally meaningful groups in all 3 cohorts was achieved by merging data with the MyPyramid Equivalents Database (MPED) and calculating components using MPEDs (28). This is a standardized, guidance-based food grouping method that systematizes calculation of food group and nutrient amounts by disaggregating foods into their components and allocating those components to 1 of 32 food groups and subgroups. MPED units are cup and ounce equivalents. The MPED groups and subgroups were used to score each dietary index.

For the present analysis, high-quality dietary intake was defined based on the HEI-2015 (6). The HEI-2015 includes scores for 13 components (7). As shown in **Supplemental Table 2**, the HEI-2015 includes 9 adequacy components, each assigned either 5 or 10 points [total fruits (5), whole fruits (5), total vegetables (5), greens & beans (5), whole grains (10), dairy (10), total protein foods (5), seafood & plant protein (5), fatty acids (10)], and 4 moderation components, each assigned 10 points (refined grains, sodium, added sugars, saturated fats). Most components are scored as a density (per 1000 kcal) (7).

Cohort-specific inclusion criteria and outcome definitions

In all 3 cohorts, only individuals with complete data on dietary intake, outcome status, or survival time were included. Individuals with implausible energy intakes as determined by each cohort, baseline energy intake of <600 kcal/d or >5000 kcal/d, or a baseline history of CVD or cancer (other than nonmelanoma skin cancer) were excluded (2,

29). Deaths were identified in each cohort and cause of death assigned based on information obtained from the National Death Index, medical record, and death certificate review (8–10). The all-cause mortality outcome included CVD and cancer deaths as well as deaths from other causes. In addition, final cause of death in the WHI OS was adjudicated by trained physician adjudicators (30) and the AARP investigated cause-specific mortality by using the Surveillance Epidemiology and End Results (SEER) coding system (30).

Statistical methods

In each of the 3 cohorts, the following process was applied to data analyses (see also **Supplemental Figure 1**). To allow direct comparison with earlier DPMP analyses which have been sex-specific, first, each cohort was split into men and women, where applicable, and the HEI-2015 values categorized into sex-specific quintiles. Next, each cohort was restricted further to observations in HEI-2015 quintiles 1 and 5. For quintile 1, minimum values ranged from 20 to 26 across cohorts and samples and the maximum values from 58 to 61. For quintile 5, the minimum values ranged from 76 to 78 and the maximum values from 95 to 99. Previous DPMP publications have used quintile 1 as the reference group. Then, given that the size of the data sets allowed a cross-validation approach and to avoid model-overfitting, each sex-specific data set was randomly split in half, with the first half used to identify the dietary clusters, interpret and describe clusters, and develop dietary pattern constellations (31). The second half was used to replicate and validate the clustering process and test associations with mortality outcomes. All data presented are from the second half of the sample and analyses were conducted using SAS version 9.4 (SAS Institute).

Determining dietary clusters.

A cluster analysis was conducted in HEI-2015 quintile 5 to empirically identify high-quality dietary patterns, with the HEI-2015 component variables standardized to a mean of 0 and SD of 1. The standardization removes any unequal contribution of variables due to higher variability, avoiding components with larger ranges of values having more influence on the generation of clusters. We used PROC FASTCLUS in SAS and the k-means model. The procedure groups individuals into a predetermined number of mutually exclusive clusters based on minimizing Euclidean distances within clusters and maximizing these distances between clusters (14). These distances are calculated based on the differences between an individual's vector of observed values and each cluster centroid, which is a vector of means for the variables included in the cluster analysis. Based on previous experience with cluster analysis, between 3 and 9 runs were conducted to identify the optimal number of clusters. The 3-cluster solution was selected in all cohort samples, based on interpolating between the cubic clustering criterion method, the Pseudo F method, the r-square, and a visual depiction of plotted cluster solutions. After stepping through the interpretation and grouping into constellations of dietary patterns, PROC DISTANCE was used to form the clusters in the holdout sample, using the centroids of the original clusters in the first half of the samples as input.

Descriptive analyses of clusters.

Radar graphs were used to visualize the range of intakes among the HEI-2015 components (15). A graph contains 13 axes or spokes, each representing 1 HEI-2015 component score (e.g., total fruits, whole fruits, total vegetables). The arrangement of components used here follows previous guidance and is consistent across graphs (7, 9). The dimension of the axis is a percentage, because the component scores have been converted from points to percentages and then represented on the graph with a line connecting each component's value. For example, for total fruits, 0.8 cup equivalents/1000 kcal is considered optimal adherence and would receive a score of 5 out of 5 which would be converted to 100% for depiction, whereas 0.64 cup equivalents/1000 kcal would receive a score of 4 out of 5 corresponding to 80%. The conventional representation of the radar graph, referred to as a truncated radar graph (**Supplemental Figure 2**), depicts the adherence on a scale from 0% to 100% (7, 9). Achieving a perfect component score relative to each of the 13 component criteria would be displayed as a line around the perimeter of the truncated radar graph.

We developed a variation of the radar graphs that depicts the full range of adherence values by converting each score to a percentage ranging from 0 to infinity (**Figure 1**). For example, an individual consuming 1.6 cup equivalents of total fruits/1000 kcal would be represented at 200%. We refer to this depiction as the untruncated radar graph. For visualization, the length of the scale/maximum percentage of the axes was determined by the highest value of a percentage in excess of the criteria observed in these analyses. For adequacy dietary components, the untruncated radar graphs do not have a maximum value, but for moderation components (refined grain, sodium, added sugars, and saturated fats) intakes of 0 represent both the best possible absolute adherence and the minimum, and correspond to 172%, 222%, 133%, and 200% of adherence, respectively. To facilitate interpretation of the radar graphs, 3 evaluative labels were assigned: "below goal" (<65%), "beyond goal" (150%–200%), and "exceeding goal" (>200%).

Shape analyses of radar graphs.

To identify correspondences between radar graphs, we conducted a visual inspection and alignment followed by a shape analysis, which is used in medical image processing applications and is based on identifying landmark-based shape deformation (16, 17). This method was applied to the untruncated radar graphs for the 15 clusters (e.g., 5 populations with 3 clusters each). This yielded a 15 × 15 shape-dissimilarity matrix (**Supplemental Table 3**). The smaller the value the larger the shape similarity, which was interpreted to identify constellations (groupings of clusters) as follows. First, to identify a starting point for the constellation formation process, pairs of clusters with the smallest absolute dissimilarity value were identified. This resulted in 6 pairs of clusters, each of which paired 1 female and 1 male cluster within the AARP and within the MEC. These pairs were rank ordered according to their dissimilarity values. Next, we evaluated each WHI OS cluster sequentially, matching it to the aforementioned pairs, with the goal of minimizing dissimilarity. In a last step, we evaluated whether any pairs from step 1 could be combined, again using the minimization of dissimilarity criterion. In the end, this resulted in 5 constellations, 2 containing 5 clusters, 2 containing 2 clusters, and 1 containing a single cluster. During this process, we did not allow for clusters within the same cohort sample to be paired (i.e., AARP female clusters 1 and 3) because the cluster analysis had determined the 3-cluster solution to be optimal. In summary, the shape analysis allowed an overarching matching of clusters into constellations containing similar clusters and facilitated the development of a grouping scheme producing constellations that transcended the individual cohorts (**Supplemental Tables 4** and **5**).

Association of dietary clusters and constellations of patterns with mortality outcomes.

Cox proportional hazards models were conducted to evaluate the constellations, by focusing on the associations between the clusters identified in quintile 5 relative to diet intake in quintile 1 and all-cause, cancer, and CVD mortality in a sex-specific manner for each cohort, using person-years as the time metric. Using the cohort- and sex-specific quintile 1 as reference allowed for comparability with previous DPMP publications (1–4, 8–10). Follow-up time was very consistent within cohort and similar across cohorts (mean: AARP women, 14 y; AARP men, 13 y; MEC women, 19 y; MEC men, 18 y; WHI OS women, 15 y). Multivariate HRs and 95% CIs were estimated and the proportionality assumption was not violated. All models adjusted for age in years (continuous), self-identified race/ethnicity (categorical in a cohort-appropriate manner), education (<12 y, 12 y, 13–15 y, ≥16 y; in the WHI OS postcollege education was separated and high school and less combined), marital status (yes, no; the AARP further differentiated widowed, divorced, separated, and never married for

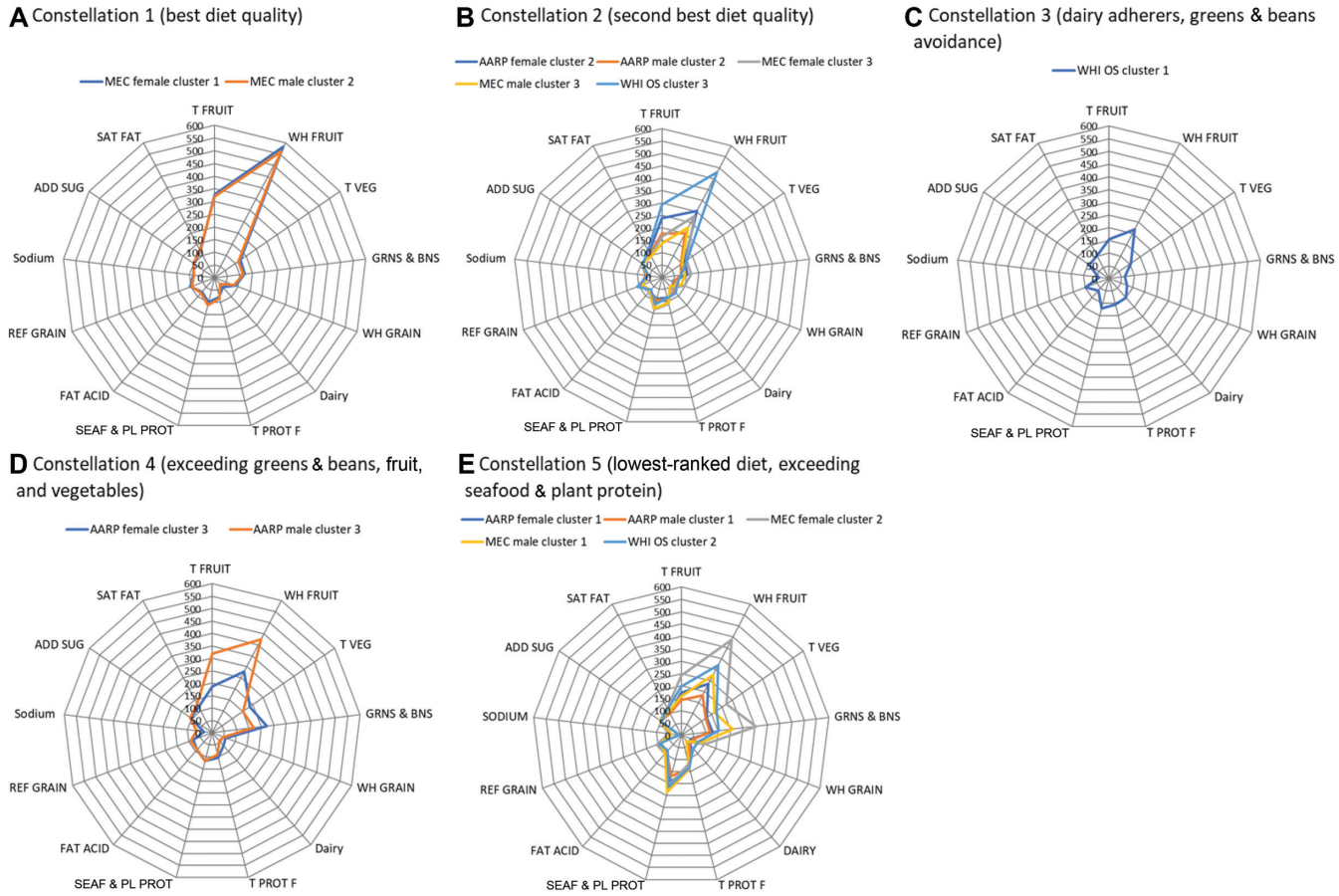

FIGURE 1 Commonalities and differences in adherence to Healthy Eating Index-2015 dietary intake recommendations across high-quality dietary intake constellations: untruncated radar graphs. (A–E) Constellations 1–5. AARP, NIH-American Association of Retired Persons Diet and Health Study; ADD SUG, added sugars; FAT ACID, fatty acids; GRNS & BNS, greens & beans; MEC, Multiethnic Cohort; REF GRAIN, refined grains; SAT FAT, saturated fats; SEAF & PL PROT, seafood & plant protein; T FRUIT, total fruits; T PROT F, total protein foods; T VEG, total vegetables; WH FRUIT, whole fruits; WH GRAIN, whole grains; WHI OS, Women's Health Initiative Observational Study.

those who were not currently married), physical activity (using cohort-specific cutoffs), smoking (never, former, current; the AARP further differentiated the number of cigarettes per day as >20 compared with ≤20/d), energy in kilocalories (continuous), BMI (in kg/m^2) (the MEC used the cutoffs <24.5, 25–29, and ≥30; the WHI OS and AARP included additional categories: <18.5, 20–34.9, 35–39.9, and ≥40), alcohol in grams per day (continuous), and diabetes at baseline (yes, no). Models for women in addition adjusted for use of hormone replacement therapy as never, former, or current users (except in the MEC: yes, no at baseline).

Results

Distribution of clusters in cohort populations

The cluster distributions varied substantially across the cohorts, with the proportions of each cluster ranging from 16.6% to 56.9% in women and from 18.1% to 61.9% in men (Tables 1 and 2).

Median intake and average adherence to HEI-2015 component criteria according to clusters

Table 1 (women) and Table 2 (men) present the cluster distribution across cohorts and the median intake amounts of all HEI-2015 components and mean adherence according to clusters. Even though all consumed a high-quality diet, there was substantial variation in the component intakes between clusters and across cohorts. Components whose median varied more strongly across clusters (within cohorts) included total fruits, whole fruits, total vegetables, greens & beans, total protein foods, seafood & plant protein, and saturated fats. Components whose median intake values showed very little variation across clusters included whole-grain and dairy foods, fatty acids, refined grains, sodium, and added sugars. The degree to which dietary intake of some adequacy components (e.g., total fruits, whole fruits, total vegetables, greens & beans, seafood & plant protein) exceeded the recommendations in all cohorts was noteworthy, in 1 instance ≤583%. Comparing across cohorts, in all clusters and population samples the median sodium intake exceeded recommendations of ≤1.1 g/1000 kcal, even though this population was on average consuming a high-quality diet (e.g., HEI-2015 quintile 5). Refined grain intake was another moderation component for which few groups met the recommendation. However, for added sugars and saturated fats, adherence to recommendations was substantially better. In addition, there were some striking between-cohort differences in median intakes, with the MEC samples having the highest whole grain intake and the AARP the lowest.

Correspondence of clusters in constellations across cohorts using untruncated radar graphs

Given that cluster numbering is an arbitrary artifact from the clustering procedure, no correspondence between cluster

TABLE 1 Median intake amounts of HEI-2015 components and percentage adherence among dietary patterns determined with cluster analysis in HEI-2015 quintile 5 among each of the female Dietary Patterns Methods Project cohort samples[1]

Cluster number	AARP (n = 18,240)						MEC (n = 8663)						WHI OS (n = 6205)					
	1		2		3		1		2		3		1		2		3	
n (%)	3210 (17.6)		10,363 (56.8)		4667 (25.6)		2602 (30.0)		1438 (16.6)		4623 (53.4)		3534 (56.9)		1190 (19.2)		1481 (23.9)	
HEI-2015	M	%	M	%	M	%	M	%	M	%	M	%	M	%	M	%	M	%
Total fruits, cup eq/1000 kcal	1.4	173	1.9	239	1.5	187	2.6	329	1.9	241	1.3	164	1.2	155	1.6	198	2.4	294
Whole fruits, cup eq/1000 kcal	0.9	236	1.2	303	1.1	277	2.3	583	1.8	438	1.1	280	0.9	219	1.3	320	1.9	480
Total vegetables, cup eq/1000 kcal	1.4	124	1.2	112	2.0	184	1.4	123	2.4	221	1.3	120	1.1	104	1.9	173	1.3	122
Greens & beans, cup eq/1000 kcal	0.3	127	0.2	104	0.4	222	0.2	120	0.6	305	0.2	120	0.1	64	0.3	152	0.2	76
Whole grains, oz eq/1000 kcal	0.6	40	0.7	46	0.9	58	1.3	89	1.5	100	1.5	97	1.1	77	1.1	72	1.0	65
Dairy, cup eq/1000 kcal	0.7	57	1.1	85	0.9	69	0.7	50	0.4	33	0.7	57	1.3	100	0.9	73	1.1	85
Total protein foods, oz eq/1000 kcal	3.6	142	2.1	85	2.6	102	2.0	79	3.0	120	2.8	110	2.6	105	3.3	131	2.2	87
Seafood & plant protein, oz eq/1000 kcal	1.6	194	0.7	88	0.9	117	0.8	100	1.7	209	1.1	135	1.0	120	1.7	215	0.9	112
Fatty acids (ratio)	2.5	97	2.2	77	2.4	91	2.2	74	2.5	98	2.2	76	2.0	62	2.3	82	2.1	66
Refined grains, oz eq/1000 kcal	1.9	95	1.9	95	2.3	82	1.8	102	1.7	106	2.1	89	1.8	98	1.9	95	1.6	108
Sodium, g/1000 kcal	1.5	51	1.4	65	1.7	34	1.2	84	1.5	51	1.5	55	1.6	40	1.9	10	1.5	56
Added sugars, % kcal	5.8	104	7.3	96	5.8	104	6.7	99	5.3	106	6.8	98	7.8	93	6.6	100	7.8	93
Saturated fats, % kcal	7.9	100	7.0	113	6.6	117	6.4	120	6.3	121	8.1	98	7.9	101	6.4	120	6.2	122

[1]AARP, NIH-American Association of Retired Persons Diet and Health Study; HEI, Healthy Eating Index; M, median intake amounts of HEI-2015 components among high-quality dietary patterns; MEC, Multiethnic Cohort; WHI OS, Women's Health Initiative Observational Study; %, percentage adherence for each HEI-2015 component.

numbering can be assumed. Instead, data presented in Tables 1 and 2 and the results from the shape difference were utilized to identify correspondences (Supplemental Tables 3 and 4), resulting in the 5 constellations shown in Figure 1 and described in Supplemental Table 5.

Constellation 1 (31.5% of MEC women, 18.2% of MEC men) had the overall best adherence, close to 100% for the majority of HEI components (Figure 1). The truncated radar graphs for these 2 samples highlight the similarity in the shapes of these 2 clusters, where the only noteworthy shortfall was dairy intake (Supplemental Figure 2). The remarkably high adherence for whole grain of 89% in women and 83% in men, and for sodium at 84% in women and 82% in men, distinguished these 2 clusters. Moreover, these 2 clusters were among the few where intake amounts substantially exceeding goals were limited solely to total fruits and whole fruits intake.

Constellation 2 included 5 clusters, Clusters 2 in both AARP women (56.8%) and men (49.9%), Clusters 3 in both MEC women (53.3%) and men (61.9%), and Cluster 3 in WHI OS (23.9%). This constellation had sodium adherence lower than in Constellation 1, but with a range in adherence (from 55% to 65%). Another characteristic shared by Constellation 2 with Constellation 1 was almost no variation in median adherence score for 10 of the 13 HEI-2015 components.

Constellation 3 comprised a single pattern, Cluster 1 of WHI OS, 57% of the WHI OS sample. This cluster and constellation were characterized by meeting the dairy goal but were below goal on greens & beans and below goal on sodium and fatty acids.

Constellation 4 was observed only in the AARP, comprised 26.6% of AARP women (Cluster 3) and 18.3% of AARP men (Cluster 3), and was characterized by below-goal intakes for whole grain and sodium (and dairy in men only). Constellation 4 was also characterized by beyond-goal intake of total vegetables in 1 cluster and exceeding-goal intake of total vegetables in the other and beyond-goal/exceeding-goal intakes of greens & beans.

Constellation 5 included AARP females Cluster 1 (17.6%), AARP males Cluster 1 (31.8%), MEC females Cluster 2 (15.1%), MEC males Cluster 1 (20%), and WHI OS Cluster 2 (19.2%). Constellation 5 was primarily characterized by seafood & plant protein intake exceeding goals (Figure 1) paired with below-goal dairy intake (except in WHI OS women, among whom intake was low but not <65%) plus below-goal sodium intake. In AARP women and men, this constellation in addition included below-goal whole grain intake. Of the 5 constellations, this one showed the most variation in median adherence for 3 of the 13 HEI-2015 components.

Association of constellations with mortality outcomes

Figure 2 depicts results from fully adjusted multivariate models for the associations of each of the constellations with all 3 mortality outcomes, whereas **Supplemental Table 6** provides the underlying sample sizes and **Supplemental Table 7** the numeric results. The 2 high-quality dietary clusters in Constellation 1 (MEC high adherers, best diet, exceeding fruit, low dairy) were associated with significantly lower all-cause mortality ($MEC_{female\ c1}$ HR: 0.84; 95% CI: 0.78, 0.92; $MEC_{male\ c2}$ HR: 0.75; 95% CI: 0.68, 0.83) and CVD mortality ($MEC_{female\ c1}$ HR: 0.83; 95% CI: 0.72, 0.96; $MEC_{male\ c2}$ HR: 0.75; 95% CI: 0.64, 0.89) than individuals in quintile 1. With respect to cancer mortality, $MEC_{male\ c2}$ exhibited significantly

TABLE 2 Median intake amounts of HEI-2015 components and percentage adherence among dietary patterns determined with cluster analysis in HEI-2015 quintile 5 among each of the male Dietary Patterns Methods Project cohort samples[1]

	AARP ($n = 24,059$)						MEC ($n = 7059$)					
Cluster number	1		2		3		1		2		3	
n (%)	7660 (31.8)		12,007 (49.9)		4392 (18.3)		1408 (20.0)		1284 (18.1)		4367 (61.9)	
HEI-2015 component	M	%	M	%	M	%	M	%	M	%	M	%
Total fruits, cup eq/1000 kcal	1.1	143	1.4	177	2.5	318	1.3	159	2.6	320	1.1	138
Whole fruits, cup eq/1000 kcal	0.7	183	0.8	201	1.7	425	1.1	275	2.2	561	0.9	228
Total vegetables, cup eq/1000 kcal	1.3	121	1.0	93	1.7	151	1.8	163	1.2	113	1.1	97
Greens & beans, cup eq/1000 kcal	0.2	116	0.2	76	0.3	169	0.4	210	0.2	113	0.2	94
Whole grains, oz eq/1000 kcal	0.7	50	0.7	50	0.7	48	1.3	85	1.2	83	1.3	85
Dairy, cup eq/1000 kcal	0.7	50	1.0	73	0.5	42	0.4	30	0.4	33	0.6	48
Total protein foods, oz eq/1000 kcal	3.4	136	2.3	93	2.2	89	3.5	140	2.1	83	2.7	106
Seafood & plant protein, oz eq/1000 kcal	1.4	169	0.8	95	0.9	116	1.9	236	0.9	113	1.0	130
Fatty acids (ratio)	2.4	89	2.2	73	2.4	90	2.5	98	2.3	81	2.1	72
Refined grains, oz eq/1000 kcal	2.1	87	2.0	93	2.0	93	2.0	90	1.9	97	2.2	84
Sodium, g/1000 kcal	1.6	41	1.4	64	1.4	64	1.6	40	1.3	82	1.5	57
Added sugars, % kcal	5.3	106	6.9	98	5.1	107	5.2	107	6.3	101	7.0	97
Saturated fats, % kcal	8.1	98	7.5	107	5.6	129	7.4	109	6.2	123	8.4	95

[1] AARP, NIH-American Association of Retired Persons Diet and Health Study; HEI, Healthy Eating Index; M, median intake amounts of HEI-2015 components among high-quality dietary patterns; MEC, Multiethnic Cohort; WHI OS, Women's Health Initiative Observational Study; %, percentage adherence for each HEI-2015 component.

lower cancer mortality (HR: 0.68; 95% CI: 0.56, 0.83) but not $MEC_{female\ c1}$.

The 5 clusters in Constellation 2 (cross-cutting, exceeding fruit and sodium) were associated with significantly lower all-cause mortality ($AARP_{female\ c2}$ HR: 0.73; 95% CI: 0.69, 0.78; $AARP_{male\ c2}$ HR: 0.77; 95% CI: 0.73, 0.82; $MEC_{female\ c3}$ HR: 0.78; 95% CI: 0.73, 0.84; $MEC_{male\ c3}$ HR: 0.78; 95% CI: 0.72, 0.83; WHI_{c3} HR: 0.80; 95% CI: 0.69, 0.93) than individuals in quintile 1. Four of the 5 clusters were also associated with significantly lower CVD mortality ($AARP_{female\ c2}$ HR: 0.73; 95% CI: 0.65, 0.84; $AARP_{male\ c2}$ HR: 0.86; 95% CI: 0.78, 0.94; $MEC_{female\ c3}$ HR: 0.74; 95% CI: 0.65, 0.85; $MEC_{male\ c3}$ HR: 0.75; 95% CI: 0.67, 0.84) with WHI OS_{c3} being the exception. Four of the 5 clusters were also associated with lower cancer mortality (significant HRs ranging from 0.72 to 0.80), the exception here being $MEC_{female\ c3}$.

Constellation 3 (WHI OS dairy adherers, greens & beans avoiders) was associated with significantly lower all-cause mortality (HR: 0.80; 95% CI: 0.72, 0.90) and cancer mortality (HR: 0.71; 95% CI: 0.58, 0.88), but not CVD mortality.

The 2 dietary clusters in Constellation 4 (AARP, exceeding greens & beans, fruit, and vegetables) were associated with significantly lower all-cause ($AARP_{female\ c3}$ HR: 0.77; 95% CI: 0.71, 0.84; $AARP_{male\ c3}$ HR: 0.84; 95% CI: 0.78, 0.90) and cancer mortality ($AARP_{female\ c3}$ HR: 0.82; 95% CI: 0.71, 0.96; $AARP_{male\ c3}$ HR: 0.81; 95% CI: 0.71, 0.93) than individuals in quintile 1. One of the 2 patterns in this constellation, $AARP_{female\ c3}$, in addition showed lower CVD mortality (HR: 0.80; 95% CI: 0.68, 0.95), but this was not observed in $AARP_{male\ c3}$.

Constellation 5 (cross-cutting, exceeding seafood & plant protein) exhibited significantly lower all-cause mortality than quintile 1 for 4 of the 5 population samples, including AARP and MEC men and women for all-cause mortality ($AARP_{female\ c1}$ HR: 0.76; 95% CI: 0.69, 0.84; $AARP_{male\ c1}$ HR: 0.78; 95% CI: 0.73, 0.83; $MEC_{female\ c2}$ HR: 0.82; 95% CI: 0.73, 0.91; $MEC_{male\ c1}$ HR: 0.78; 95% CI: 0.71, 0.86), with WHI OS_{c2} women being suggestive (HR: 0.85; 95% CI: 0.72, 1.01). The AARP and MEC clusters were also associated with significantly lower CVD mortality ($AARP_{female\ c1}$ HR: 0.75; 95% CI: 0.61, 0.91; $AARP_{male\ c1}$ HR: 0.86; 95% CI: 0.77, 0.96; $MEC_{female\ c2}$ HR: 0.79; 95% CI: 0.66, 0.94; $MEC_{male\ c1}$ HR: 0.74; 95% CI: 0.63, 0.88) but not WHI OS_{c2}. Only $AARP_{male\ c1}$ (HR: 0.79; 95% CI: 0.71, 0.88) showed significantly lower cancer mortality.

Discussion

This exploration of the multidimensional nature of high-quality dietary intake, using cluster analysis and shape analysis, confirmed our hypothesis that there is indeed variation in eating types within the high-quality dietary intake spectrum, because we found 3 healthy dietary patterns in each cohort's HEI-2015 quintile 5.

Visual inspection of radar graphs and evaluation of tabular data revealed both differences and similarities in high-quality dietary patterns. Radar graphs have typically been used to show differences between guideline-adherent high-quality and very-low-quality dietary intake (7–9). However, a limitation of truncated radar graphs is they do not visualize intakes beyond goals. Thus, we extended the radar graph concept to untruncated radar graphs, which visualize intake amounts exceeding recommendations. High intakes were observed for 6 of the 13 HEI-2015 components: total fruits, whole fruits, total vegetables, seafood & plant protein, added sugars, and saturated fats. The untruncated radar graphs revealed that intake of total fruits and whole fruits exceeded goals in all cohort samples, ranging from 138% to 329% and 183% to 583%, respectively. The truncated radar graphs highlighted that sodium goals were never fully met, which is consistent with average intake in the total US population (32). Considered together, this may suggest that whereas the high intake of whole fruit in these high-quality diets may be indicative of a stronger orientation to unprocessed plant products, one might speculate that there are other dietary practices, such as consumption of highly processed salty snacks, that are harder to change. With respect to grains, whereas high refined and low whole grain

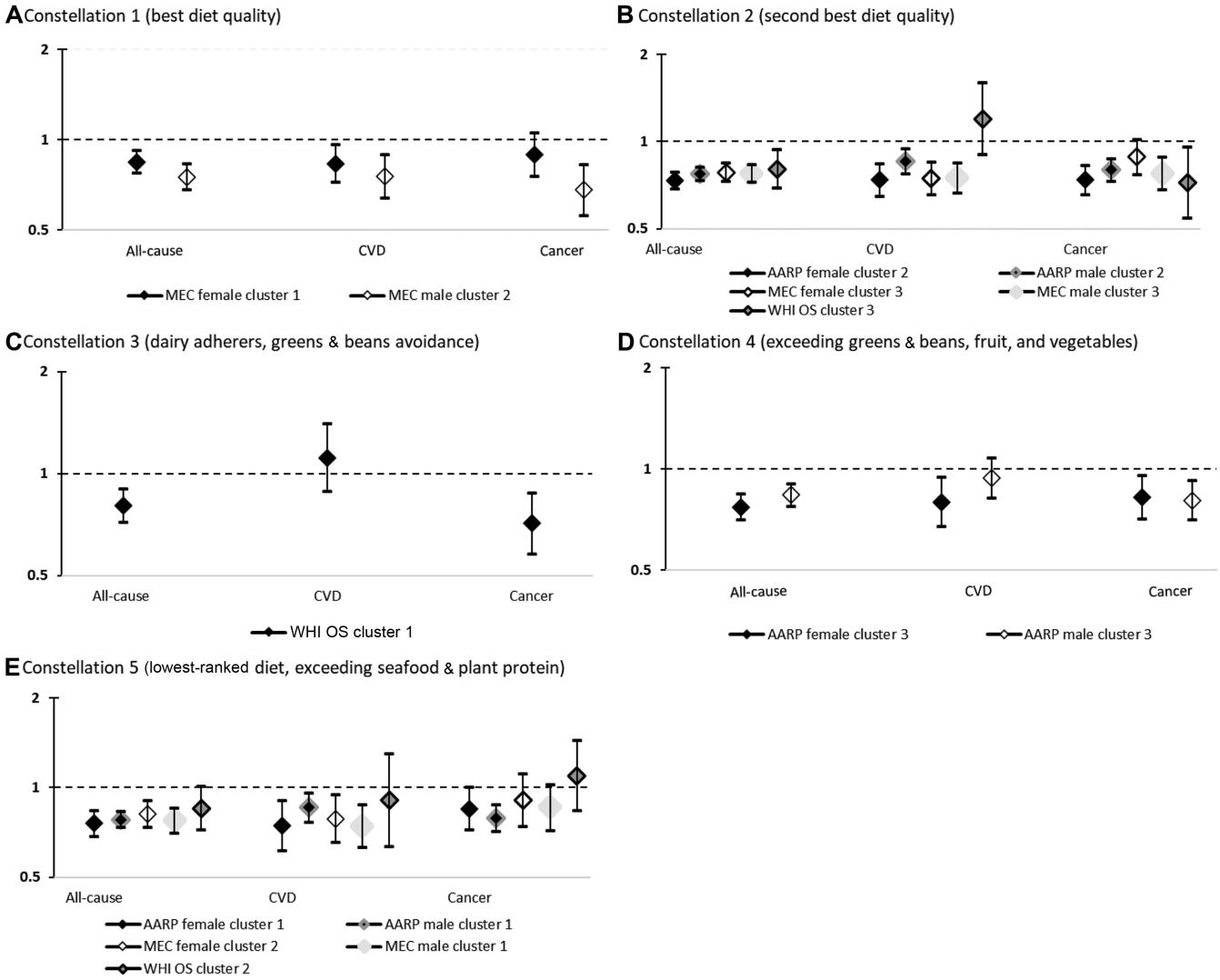

FIGURE 2 Association of high-quality diet intake patterns within HEI-2015 quintile 5 with all-cause, CVD, and cancer mortality, according to dietary intake constellation. (A–E) Constellations 1–5. Data presented are HRs and 95% CIs from multivariate Cox proportional hazards models, comparing each cohort- and sex-specific cluster with the corresponding quintile 1 of HEI-2015. All models adjusted for age, race/ethnicity, education, marital status, physical activity, smoking, BMI, kilocalories, alcohol consumption, and diabetes and in women in addition for hormone replacement therapy. AARP, NIH-American Association of Retired Persons Diet and Health Study; CVD, cardiovascular disease; HEI, Healthy Eating Index; MEC, Multiethnic Cohort; WHI OS, Women's Health Initiative Observational Study.

intake continue to be problematic in the United States (33, 34), in our high-quality clusters the average refined grain intake started approaching the recommendations, although this was not true for whole grains. In totality, this visualization revealed the presence of some overarching dietary intake themes that cut across all patterns and specific variations that distinguished the different high-quality dietary intake constellations.

Comparing clusters across cohorts revealed that dietary intake in the MEC samples was closer to goal than in the AARP and WHI OS and there was less variation in adherence in the MEC samples than in the AARP and WHI OS. Similarities in high-quality dietary intake across sex have been noted previously (9), but we in addition found that the similarities between the sexes in a given cohort were stronger than the similarities across cohorts.

In the United States, both distinct sociocultural and regional dietary intake habits coexist with behaviors that transcend regions and cultures (12, 35–39). Thus, to identify potential shared dietary intake constellations across the 3 cohorts, visual examination was supplemented with pattern recognition principles and a formal shape analysis applied to the untruncated radar graph data (16). The 3 clusters observed in each of the cohort samples were mapped onto a total of 5 distinct constellations. Given the inherent limitation that results of highly data-driven methods such as cluster analyses generally are not suited for identification of generalizable findings, it is noteworthy that 2 of the 5 constellations were identified in all cohorts and samples. This suggests there are some common underlying patterns of healthy dietary intake that transcend sociocultural and regional diet differences in the United States.

The magnitude and strength of the associations of the high-quality dietary constellations with the mortality outcomes were very similar in 2 of the 3 cohorts to those observed in our earlier work using the HEI-2010 (4). All high-quality dietary intake patterns (i.e., all clusters and all constellations) were associated with a 15%–26% significantly lower risk of death due to all causes than dietary intake in quintile 1, and this was found in all cohorts except in WHI OS cluster 2, independent

of known confounders. However, the relatively tight range of point estimates with 95% CIs frequently overlapping between clusters and constellations suggests that further distinction between dietary patterns within this high-quality intake range may not enhance or differentiate the association with mortality outcomes, beyond that observed for high-quality diet alone (8–10).

The high-quality intake patterns were also consistently and significantly associated with a 16%–25% lower risk of CVD mortality in the AARP and MEC cohorts. However, in the present WHI OS analysis, which incorporated 6 additional years of follow-up time, none of the HEI-2015-based diet clusters was associated with significantly lower CVD mortality, which mirrors a recent analysis of the HEI-2015 in the WHI OS but differs from the previous WHI OS findings using the HEI-2010 (4, 10). One possible explanation is that there is probably some residual, uncontrolled confounding because medications used to treat or prevent CVD, which are used for the duration of life, were not included in the models. With respect to cancer mortality, our findings were more heterogeneous than previous work (4) because only 5 of the 9 high-quality dietary clusters were associated with cancer mortality. No significant associations with cancer mortality were observed in the MEC clusters, which may have been due to loss in power from our reduced testing sample size and cluster stratifications compared with earlier MEC findings indicating that 16%–20% lower cancer mortality was associated with high-quality HEI-2015-based dietary intake (9). In the AARP and WHI OS, high-quality dietary intake clusters/patterns were associated with 15%–28% lower cancer mortality than quintile 1, except for WHI OS cluster 2 not being associated. However, here too the overlapping CIs between clusters and constellations suggest the empirical distinctions represented by the constellations do not necessarily translate into meaningful differences in strengths or magnitudes of associations.

Limitations of this study include that assignment into a dietary pattern was based on administration of a single FFQ in each cohort at baseline and thus does not account for potential changes in dietary intakes over time (10). Moreover, HEI components such as sodium, whole grains, and seafood may not be quantified well on an FFQ. Measurement error, particularly the systematic measurement error in self-reported dietary assessment, is an important limitation of this study. Our approach to testing the associations between dietary cluster patterns and mortality outcomes was likely overly conservative because we developed the clusters and constellations on one-half of the cohort samples and reserved the other half for testing, negatively affecting statistical power. No information was available on stage at cancer diagnosis and treatment which are strong predictors of mortality. Even though we adjusted for many covariates, residual confounding cannot be excluded. By design, the analysis was constrained by the populations included, the diet assessment tools (which differed between cohorts), and the associated variables used to define dietary patterns. These decisions include inherent limitations which may have influenced the formation of clusters and constellations, including lack of representativeness to reflect all possible dietary patterns, methods to assess dietary patterns, and the database and index used to define eating constructs (e.g., including fruits as a food group may mask potential synergism with a specific fruit and other foods based on how the foods are eaten). The radar graphs depiction assumed linearity and as multidimensionality methodology advances this assumption should be tested. Finally, the study's focus on quintiles 5 and 1 does not allow inferences to the middle range of dietary intake quality.

Among the strengths of this rigorously standardized consortium effort is the use of data from 3 very large ongoing US cohorts of mid- to older-age women and men enrolled in the mid-1990s representing diverse race and ethnicity. All cohorts used validated FFQs and had lengthy mortality follow-up. We applied an a priori–defined set of standardized analyses uniformly to all cohort samples, which allows for direct comparisons. Also, utilizing not only truncated but untruncated radar graphs and shape analysis allowed us to capture more of the richness of dietary intake data, which has been identified as a gap in current research (11).

This study demonstrated that most high-quality dietary intake patterns were associated with a statistically significant 15%–26% lower risk of mortality due to all causes than people in dietary intake quintile 1, independent of known confounders. The findings highlight differences in consumption patterns in people with very high-quality dietary intake, pointing out intakes markedly in excess of recommendations for select food groups (e.g., total and whole fruits) and intakes that still leave room for improvement (e.g., sodium, dairy, refined grains). Although our study does not suggest that the intake constellations observed in the high-quality range differ with respect to their associated mortality, more research is needed to understand whether exceeding recommendations on 1 dietary component can offset suboptimal adherence on another component. In conclusion, this cluster analysis–based study identified multiple ways to achieve a healthy diet.

Acknowledgments

We thank the WHI investigators and staff for their dedication, and the study participants for making the program possible. A full listing of WHI investigators can be found at: https://www-whi-org.s3.us-west-2.amazonaws.com/wp-content/uploads/WHI-Investigator-Long-List.pdf. The authors thank Lisa Kahle for conducting the statistical analyses. ADL conceptualized the study, provided oversight for data analyses, wrote and edited the manuscript. EW, JLL, CJB, MLN, SW, BEH, and LFT contributed to drafting the manuscript and contributed to critical revisions of the manuscript for important intellectual content. SW conducted the shape analyses. All authors have read and approved the final manuscript.

References

1. Reedy J, Krebs-Smith SM, Miller PE, Liese AD, Kahle LL, Park Y, Subar AF. Higher diet quality is associated with decreased risk of all-cause, cardiovascular disease, and cancer mortality among older adults. J Nutr 2014;144(6):881–9.
2. George SM, Ballard-Barbash R, Manson JAE, Reedy J, Shikany JM, Subar AF, Tinker LF, Vitolins M, Neuhouser ML. Comparing indices of diet quality with chronic disease mortality risk in postmenopausal women in the Women's Health Initiative Observational Study: evidence to inform national dietary guidance. Am J Epidemiol 2014;180(6):616–25.
3. Harmon BE, Boushey CJ, Shvetsov YB, Ettienne R, Reedy J, Wilkens LR, Le Marchand L, Henderson BE, Kolonel LN. Associations of key diet-quality indexes with mortality in the Multiethnic Cohort: the Dietary Patterns Methods Project. Am J Clin Nutr 2015;101(3):587–97.
4. Liese AD, Krebs-Smith SM, Subar AF, George SM, Harmon BE, Neuhouser ML, Boushey CJ, Schap TE, Reedy J. The Dietary Patterns Methods Project: synthesis of findings across cohorts and relevance to dietary guidance. J Nutr 2015;145(3):393–402.
5. Dietary Guidelines Advisory Committee. Scientific report of the 2015 Dietary Guidelines Advisory Committee: advisory report to the Secretary of Health and Human Services and the Secretary of

Agriculture. Washington (DC): USDA, Agricultural Research Service; 2015.
6. US Department of Health and Human Services (DHHS) and USDA. 2015–2020 Dietary Guidelines for Americans. [Internet]. 2015 8th ed. Washington (DC): US DHHS and USDA; [cited 2021 Apr 29]. Available from: http://health.gov/dietaryguidelines/2015/guidelines/.
7. Krebs-Smith SM, Pannucci TRE, Subar AF, Kirkpatrick SI, Lerman JL, Tooze JA, Wilson MM, Reedy J. Update of the Healthy Eating Index: HEI-2015. J Acad Nutr Diet 2018;118(9):1591–602.
8. Reedy J, Lerman JL, Krebs-Smith SM, Kirkpatrick SI, Pannucci TRE, Wilson MM, Subar AF, Kahle LL, Tooze JA. Evaluation of the Healthy Eating Index-2015. J Acad Nutr Diet 2018;118(9):1622–33.
9. Panizza CE, Shvetsov YB, Harmon BE, Wilkens LR, Le Marchand L, Haiman C, Reedy J, Boushey CJ. Testing the predictive validity of the Healthy Eating Index-2015 in the Multiethnic Cohort: is the score associated with a reduced risk of all-cause and cause-specific mortality? Nutrients 2018;10(4):452.
10. George SM, Reedy J, Cespedes Feliciano EM, Aragaki A, Caan BJ, Kahle L, Manson JE, Rohan TE, Snetselaar LG, Tinker LF, et al. Alignment of dietary patterns with the Dietary Guidelines for Americans 2015–2020 and risk of all-cause and cause-specific mortality in the Women's Health Initiative Observational Study. Am J Epidemiol 2021;190(5):886–92.
11. Reedy J, Subar AF, George SM, Krebs-Smith SM. Extending methods in dietary patterns research. Nutrients 2018;10(5):571.
12. Liese AD, Schulz M, Moore CG, Mayer-Davis EJ. Dietary patterns, insulin sensitivity and adiposity in the multi-ethnic Insulin Resistance Atherosclerosis Study population. Br J Nutr 2004;92(6):973–84.
13. Reedy J, Wirfält E, Flood A, Mitrou PN, Krebs-Smith SM, Kipnis V, Midthune D, Leitzmann M, Hollenbeck A, Schatzkin A, et al. Comparing 3 dietary pattern methods—cluster analysis, factor analysis, and index analysis—with colorectal cancer risk: the NIH-AARP Diet and Health Study. Am J Epidemiol 2010;171(4):479–87.
14. Romesburg H. Cluster analysis for researchers. Belmont (CA): Lifetime Learning Publications; 1984.
15. Krebs-Smith S, Wilson M, Reedy J. Visualization of dietary patterns. FASEB J 2015;29(S1):131.2 (abstr).
16. Wang S, Ji JX, Liang Z-P. Landmark-based shape deformation with topology-preserving constraints. Proceedings of the 9th IEEE International Conference on Computer Vision; 2003 Oct 13–16; Nice, France. Manhattan (NY): IEEE; 2003. Vol. 2. 923–30.
17. Niessen W, Li S, Wang S. Special issue on shape modeling in medical image analysis. Comput Vis Image Underst 2013;117(9):965.
18. National Cancer Institute. NCI DPMP website. Bethesda (MD): National Cancer Institute; 2018; [cited 2021 Mar 19]. Available from: https://epi.grants.cancer.gov/dietary-patterns/.
19. Thompson FE, Kipnis V, Midthune D, Freedman LS, Carroll RJ, Subar AF, Brown CC, Butcher MS, Mouw T, Leitzmann M, et al. Performance of a food-frequency questionnaire in the US NIH–AARP (National Institutes of Health–American Association of Retired Persons) Diet and Health Study. Public Health Nutr 2008;11(2):183–95.
20. Thompson FE, Subar AF, Brown CC, Smith AF, Sharbaugh CO, Jobe JB, Mittl B, Gibson JT, Ziegler RG. Cognitive research enhances accuracy of food frequency. J Am Diet Assoc 2002;102(2):212–25.
21. Stram DO, Hankin JH, Wilkens LR, Pike MC, Monroe KR, Park S, Henderson BE, Nomura AMY, Earle ME, Nagamine FS, et al. Calibration of the dietary questionnaire for a multiethnic cohort in Hawaii and Los Angeles. Am J Epidemiol 2000;151(4):358–70.
22. Block G, Hartman A, Dresser C, Carroll M, Gannon J, Gardner LA. A data-based approach to diet questionnaire design and testing. Am J Epidemiol 1986;124(3):453–69.
23. Patterson RE, Kristal AR, Tinker LF, Carter RA, Bolton MP, Agurs-Collins T. Measurement characteristics of the Women's Health Initiative food frequency questionnaire. Ann Epidemiol 1999;9(3):178–87.
24. Schatzkin A, Subar AF, Thompson FE, Harlan LC, Tangrea J, Hollenbeck AR, Hurwitz PE, Coyle L, Schussler N, Michaud DS, et al. Design and serendipity in establishing a large cohort with wide dietary intake distributions: the National Institutes of Health–American Association of Retired Persons Diet and Health Study. Am J Epidemiol 2001;154(12):1119–25.
25. National Cancer Institute. NIH-AARP: Diet and Health Study. Questionnaire. 2018. [Internet]. Bethesda (MD): National Cancer Institute; [cited 2021 Apr 29]. Available from: https://dietandhealth.cancer.gov/index.html.
26. University of Hawai'i'Cancer Center, University of Southern California. The Multiethnic Cohort Study: participant questionnaires. [Internet]. 2018 Honolulu (HI): University of Hawai'i Cancer Center; [cited 2021 Apr 29]. Available from: https://www.uhcancercenter.org/mec.
27. Fred Hutchinson Cancer Research Center. Women's Health Initiative: forms. [Internet]. 2021. Seattle (WA): Women's Health Initiative; [cited 2021 Apr 29]. Available from: https://www.whi.org/.
28. USDA Agricultural Research Service. MyPyramid Equivalents Database for USDA survey food codes. Version 1.0. Washington (DC): USDA, Agricultural Research Service; 2018.
29. Park S-Y, Shvetsov YB, Kang M, Setiawan VW, Wilkens LR, Le Marchand L, Boushey CJ. Changes in diet quality over 10 years are associated with baseline sociodemographic and lifestyle factors in the Multiethnic Cohort study. J Nutr 2020;150(7):1880–8.
30. National Cancer Institute. SEER Cause of Death Recode 1969+ (04/16/2012). [Internet]. Bethesda (MD): National Cancer Institute; 2012 [cited 2021 Mar 19]. Available from: https://seer.cancer.gov/codrecode/1969_d04162012/index.html.
31. Hastie T, Tibshirani R, Friedman J. The elements of statistical learning: data mining, inference, and prediction. 2nd ed. Springer Series in Statistics. New York: Springer Science+Business Media; 2009.
32. Rehm CD, Peñalvo JL, Afshin A, Mozaffarian D. Dietary intake among US adults, 1999–2012. JAMA 2016;315(23):2542–53.
33. Ahluwalia N, Herrick KA, Terry AL, Hughes JP. Contribution of whole grains to total grains intake among adults aged 20 and over: United States, 2013–2016. NCHS Data Brief 2019;(341):1–8.
34. Lin B-H, Yen ST. The U.S. grain consumption landscape: who eats grain, in what form, where, and how much? ERR-50. Washington (DC): USDA, Economic Research Service; 2007.
35. Coates RJ, Monteilh CP. Assessments of food-frequency questionnaires in minority populations. Am J Clin Nutr 1997;65(4 Suppl):1108S–15S.
36. Vadiveloo M, Perraud E, Parker HW, Juul F, Parekh N. Geographic differences in the dietary quality of food purchases among participants in the nationally representative Food Acquisition and Purchase Survey (FoodAPS). Nutrients 2019;11(6):1233.
37. Kant AK, Graubard BI. Secular trends in regional differences in nutritional biomarkers and self-reported dietary intakes among American adults: National Health and Nutrition Examination Survey (NHANES) 1988–1994 to 2009–2010. Public Health Nutr 2018;21(5):927–39.
38. Rodriguez LA, Jin Y, Talegawkar SA, de Oliveira Otto MC, Kandula NR, Herrington DM, Kanaya AM. Differences in diet quality among multiple US racial/ethnic groups from the Mediators of Atherosclerosis in South Asians Living in America (MASALA) study and the Multi-Ethnic Study of Atherosclerosis (MESA). J Nutr 2020;150(6):1509–15.
39. Schaberg MN, Smith KS, Greene MW, Frugé AD. Characterizing demographic and geographical differences in health beliefs and dietary habits related to colon cancer risk in US adults. Front Nutr 2020;7:568643.