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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

Stephanie M. George*, Rachel Ballard-Barbash, JoAnn E. Manson, Jill Reedy, James M. Shikany, Amy F. Subar, Lesley F. Tinker, Mara Vitolins, and Marian L. Neuhouser

* Correspondence to Dr. Stephanie M. George, 9609 Medical Center Drive, Room 3E408, MSC 9762, Bethesda, MD 20892-9762 (e-mail: stephanie.george@nih.gov).

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Poor diet quality is thought to be a leading risk factor for years of life lost. We examined how scores on 4 commonly used diet quality indices—the Healthy Eating Index 2010 (HEI), the Alternative Healthy Eating Index 2010 (AHEI), the Alternate Mediterranean Diet (aMED), and the Dietary Approaches to Stop Hypertension (DASH)—are related to the risks of death from all causes, cardiovascular disease (CVD), and cancer among postmenopausal women. Our prospective cohort study included 63,805 participants in the Women's Health Initiative Observational Study (from 1993–2010) who completed a food frequency questionnaire at enrollment. Cox proportional hazards models were fit using person-years as the underlying time metric. We estimated multivariate hazard ratios and 95% confidence intervals for death associated with increasing quintiles of diet quality index scores. During 12.9 years of follow-up, 5,692 deaths occurred, including 1,483 from CVD and 2,384 from cancer. Across indices and after adjustment for multiple covariates, having better diet quality (as assessed by HEI, AHEI, aMED, and DASH scores) was associated with statistically significant 18%–26% lower all-cause and CVD mortality risk. Higher HEI, aMED, and DASH (but not AHEI) scores were associated with a statistically significant 20%–23% lower risk of cancer death. These results suggest that postmenopausal women consuming a diet in line with a priori diet quality indices have a lower risk of death from chronic disease.

diet; diet quality indices; mortality risk; postmenopausal women; prospective cohort study

Abbreviations: AHEI, Alternative Healthy Eating Index 2010; aMED, Alternate Mediterranean Diet; BMI, body mass index; CI, confidence interval; CVD, cardiovascular disease; DASH, Dietary Approaches to Stop Hypertension; DPMP, Dietary Patterns Methods Project; FFQ, food frequency questionnaire; HEI, Healthy Eating Index 2010; HR, hazard ratio; MET, metabolic equivalent; WHI OS, Women's Health Initiative Observational Study.

Cardiovascular disease (CVD) and cancer are the leading causes of death among women in the United States (1), and mortality rates from these diseases are increasing (2). Poor diet quality is thought to be a leading risk factor for years of life lost and years lived with chronic disability (2). To date, most dietary guidance to promote health is based largely on data about single foods and nutrients, but foods are not consumed in isolation. There has been growing interest in studying overall diet quality, an approach that takes into account the complexity of the diet and the potentially synergistic or antagonistic effects of all individual dietary components (3). Diet quality indices are increasingly being used in epidemiologic studies (3). However, the methods for measuring diet quality and analyzing its relationship with the risk of death vary across studies, and this has hampered the formulation of public health recommendations with regard to dietary patterns. The 2010 Dietary Guidelines for Americans dedicated an entire chapter to discussing the health benefits of eating a high-quality diet, but indicated that there was not yet enough evidence to provide a definitive recommendation related to diet quality and health outcomes (4).

The assessment of associations between a priori diet quality indices and health outcomes may inform policy with respect to dietary guidelines, because these measures provide a common metric for comparing findings across populations. In response to this critical need, the National Cancer Institute (Rockville, Maryland) initiated the Dietary Patterns Methods Project (DPMP) and formed a collaboration among investigators from 3 US cohorts—the Women's Health Initiative Observational Study (WHI OS), the National Institutes of Health–AARP Diet and Health Study, and the Multiethnic Cohort Study. The goal of the DPMP is to apply consistent, standardized methodologies and to systematically examine the associations of common diet quality indices and mortality risk. The purpose of this report is to present findings from the WHI OS.

The WHI OS presents a unique opportunity to study these relationships among postmenopausal women and inform the 2015 Dietary Guidelines for Americans for this population. Among 63,805 postmenopausal women, we examined how scores on 4 key commonly used a priori diet quality indices—the Healthy Eating Index 2010 (HEI) (5–7), the Alternative Healthy Eating Index 2010 (AHEI) (8, 9), the Alternate Mediterranean Diet (aMED) (10), and the Dietary Approaches to Stop Hypertension (DASH) (11)—are related to risks of death from any cause, from CVD, and from cancer. In all of these indices, higher scores correspond with a better-quality diet.

METHODS

The WHI has been previously described in depth (12–14). Briefly, between 1993 and 1998, through 40 clinical centers throughout the United States, postmenopausal women who were 50–79 years of age at study entry were recruited into either a clinical trials component ($n = 68{,}132$) or the WHI OS ($n = 93{,}676$ women). The clinical trials component and observational study conducted closeout activities in 2004–2005, and the participants were invited to continue being followed in the 2005–2010 WHI Extension Study through September 30, 2010. Written informed consent was obtained from all study participants. Procedures and protocols were approved by institutional review boards at all participating institutions. A standardized written protocol, centralized training of staff, and quality assurance visits by the clinical coordinating center were used to ensure uniformity of data collection.

The present sample was drawn from the 93,676 women participating in the WHI OS. Of these, we excluded those with incomplete diet data ($n = 96$), implausible energy intakes of less than 600 kcals/day or more than 5,000 kcals/day ($n = 3{,}570$), prior diagnosis of CVD or cancer (25,794), or missing information on diabetes status ($n = 411$), because the absence of diabetes information was highly associated with mortality risk in the WHI. Our sample for analysis was 63,805 women.

At enrollment, participants reported demographic characteristics, health behaviors, and medical histories using self-administered standardized questionnaires. We categorized risk factors as follows: race/ethnicity (white, black, Hispanic, other, or missing); educational level (high school or below, some college, college, postgraduate, or missing); marital status (married or living as married, single/widowed/divorced, or missing), smoking status (never, past, or current); diabetes (no or yes); and hypertension (no, yes, or missing) or high cholesterol that required pills (no, yes, or missing). In WHI's Measurement Precision Study, questionnaire items on demographic characteristics and medical conditions were shown to be reliable (weighted $\kappa > 0.8$) (13). Self-reported physical activity was measured using the WHI brief physical activity inventory, which has been shown to be reliable (weighted κ ranging from 0.67 to 0.71) (13) and valid when compared with accelerometer data ($r = 0.73$) (13). For each participant, we calculated metabolic equivalent (MET)-hours per week of recreational physical activity and categorized physical activity level (0, 0.1–3, 3.1–8.9, or ≥9 MET-hours/week, or missing), as described in detail previously in the WHI (15). The use of postmenopausal hormone therapies (unopposed estrogen and/or estrogen plus progesterone) via pills or patches was self-reported, and we classified women as never, past, or current users.

At the clinic visit, trained staff measured each participant's weight and height using a standardized protocol. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared, and we categorized BMI as less than 18.5, 18.5–24.9, 25.0–29.9, 30.0–34.9, or 35.0 or greater. Also at the clinic visit, trained staff measured each participant's waist circumference during expiration at the narrowest section of the torso (14).

Diet assessment

Diet was measured at enrollment using a self-administered food frequency questionnaire (FFQ) developed and validated specifically for the WHI (16) and adapted from the Health Habits and Lifestyle Questionnaire (17). The 3 sections of the WHI FFQ included 122 composite and single-food line items asking about frequency of consumption and portion size, 19 adjustment questions related to the type of fat intake, and 4 summary questions about the usual intakes of fruits and vegetables and added fats for comparison with information gathered from the line items.

The WHI FFQ was designed to capture foods relevant for multiethnic and geographically diverse population groups, and it has been shown to produce reliable ($r_{\text{all nutrients}} = 0.76$) and comparable estimates to 8 days of dietary intake from four 24-hour dietary recalls and 4-day food records ($r = 0.37$, 0.62, 0.41, and 0.36 for energy intake, percent of energy from fat, carbohydrate, and protein, respectively) (16).

The nutrient database used to analyze the WHI FFQ was derived from the Nutrition Data Systems for Research, version 2005 (University of Minnesota, Minneapolis, Minnesota) (18, 19). The Nutrition Data Systems for Research provides nutrient information for more than 140 nutrients and compounds, including energy, saturated fat, and sodium. We measured diet quality with the following indices: 1) the HEI (5), which was created by the US Department of Agriculture (Washington, DC) and the National Cancer Institute and aligns with the 2010 US Dietary Guidelines for Americans (4); 2) the AHEI, which was created on the basis of dietary guidance with modification to include factors thought to influence chronic disease risk (8); 3) the aMED, which reflects

Table 1. Criteria for Optimal Scoring for 4 Diet Quality Indices Using Standardized Cup and Ounce Equivalents From the MyPyramid Equivalents Database[a] in the Women's Health Initiative Observational Study, 1993–2010

Index Component	Diet Quality Index			
	HEI[b]	AHEI[c]	aMED[d]	DASH[e]
Alcohol		0.5–1.5 Drinks	5–15 g	
Empty calories[f]	≤19% kcal (From solid fat, added sugars, alcohol)			
Fish	≥0.8 oz[g] eq[h]/1,000 kcal (Seafood and plant proteins)		≥ Median	
Fruit	≥0.8 cup eq/1,000 kcal (Total fruit) ≥0.4 cup eq/1,000 kcal (Whole fruit)	≥2 cup eq	≥ Median	Highest quintile
Legumes			≥ Median	
Low-fat dairy	≥1.3 cup eq/1,000 kcal			Highest quintile
Nuts		≥1 oz eq (Nuts and legumes)	≥ Median (nuts and seeds)	Highest quintile (nuts, seeds, legumes)
Oils/fats	≥2.5 (Ratio of fatty acids (PUFAs + MUFAs / SFAs))	≤0.5% (*Trans* fat) 250 mg (EPA + DHA) ≥10% (PUFAs)	> Median (ratio of MUFA to SFA)	
Red and processed meats[f]		0 oz eq	< Median	Lowest quintile
Refined grains[f]	≤1.8 oz eq/1,000 kcal			
Sodium[f]	≤1.1 g/1,000 kcal	Lowest decile		Lowest quintile
SSBs[f]		0 cup eq[i]		Lowest quintile[j]
Total protein foods	≥2.5 oz eq/1,000 kcal			
Vegetables (excluding potatoes)	≥1.1 cup eq/1,000 kcal (Total vegetables, including potatoes) ≥0.2 cup eq/1,000 kcal (Greens and beans)	≥2.5 cup eq	≥ Median	Highest quintile
Whole grains	≥1.5 oz eq/1,000 kcal	5 oz eq	≥ Median	Highest quintile

Abbreviations: AHEI, Alternative Healthy Eating Index 2010; aMED, Alternate Mediterranean Diet Score; DASH, Dietary Approaches to Stop Hypertension; DHA, docosahexaenoic acid; EPA, eicosapentaenoic acid; eq, equivalent; HEI, Healthy Eating Index 2010; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid; SFA, saturated fatty acid; SSB, sugar-sweetened beverage.

[a] From Bowman et al. (23).

[b] From Guenther et al. (5). The HEI is a 100-point scale consisting of 12 components worth 5–20 points each.

[c] From Chiuve et al. (8). The AHEI is a 110-point consisting of 11 components worth 10 points each.

[d] From Fung et al. (10). The aMED is a 9-point scale consisting of 9 components worth 1 point each.

[e] From Fung et al. (11). DASH scores range from 8–40 points; it consists of 8 components worth 1–5 points each.

[f] Components were reverse-scored, such that lower intake is associated with a better score.

[g] One ounce = 28.35 g.

[h] MyPyramid equivalents translate foods as eaten into standardized quantities of dietary components of interest; for example, an equivalent is an amount considered nutritionally equal to 1 cup in the vegetable, fruit, or dairy components or 1 ounce in the grains or protein foods components.

[i] Includes pop (i.e., soft drinks), Kool-Aid (Kraft Foods, Inc., Northfield, Illinois), orange juice, and fruit juice.

[j] Includes pop (i.e., soft drinks) and Kool-Aid.

adherence to a Mediterranean dietary pattern (10); and 4) the DASH (11), which is based on foods and nutrients emphasized or minimized in the DASH diet tested in 2 randomized controlled feeding trials (20, 21). Details about components for the diet quality indices and their contributions to total scores are shown in Table 1.

We calculated index scores using diet data in units of MyPyramid equivalents by establishing a customized link (22) between Nutrition Data Systems for Research and the MyPyramid Equivalents Database, version 2.0 (US Department of Agriculture) (23). MyPyramid equivalents translate foods, as eaten, into standardized quantities of dietary components of interest; for example, an equivalent is an amount considered nutritionally equal to 1 cup in the vegetable, fruit, and dairy components or 1 ounce (1 ounce = 28.35 g) in the grains or protein foods components. We then classified index scores into quintiles.

Ascertainment of death

Vital status of participants was collected through annual clinical center follow-up of participants and proxies. In addition, we conducted periodic searches of the National Death Index (Centers for Disease Control and Prevention, Atlanta, Georgia). Causes of death were determined by medical record and death certificate review at the WHI clinical coordinating center with oversight from the WHI physician adjudicators and outcomes committee. Death from cancer included deaths from lung, breast, ovarian, endometrial, colon, rectosigmoid, rectal, uterine, and other/unknown cancers; death from CVD included deaths from definite coronary heart disease, cerebrovascular disease, pulmonary embolism, possible coronary heart disease, and other/unknown CVD (24).

Statistical analysis

Participants were followed from study enrollment until death, loss to follow-up, or the end of the previously described WHI Extension Study on September 30, 2010. Data from participants who did not consent to the extension study and were alive at study closeout on September 12, 2005, were censored on that date.

Means, standard deviations, and frequencies of demographic and lifestyle characteristics of the study sample were calculated by quintiles of index scores. We calculated univariate Pearson correlations between index scores.

Cox proportional hazards models were fit to our data using person-years as the underlying time metric. We estimated multivariate hazard ratios and 95% confidence intervals for death from any cause, death from CVD, and death from cancer associated with increasing quintiles of index scores. The proportional hazards assumption was met by modeling interaction terms of index scores and person-years, and no statistically significant interactions were found.

We adjusted for covariates commonly examined in published studies of recommendation-based diet quality scores and mortality risk so that we could build on the existing evidence base. This covariate list was standardized in the DPMP. These included age at study entry, race/ethnicity, educational level, marital status, smoking, physical activity, daily energy intake (25), postmenopausal hormone therapy, diabetes, and BMI. Because HEI and DASH scores do not include a specific component for alcohol, those scores were also adjusted for alcohol intake. We ran additional subanalyses adjusting for hypertension and high cholesterol. Given obesity's potential role as a mediator of the relationships we examined (26, 27), we chose to explore the effect of removing BMI from the final model. We also conducted

Table 2. Characteristics of 63,805 Participants in the Women's Health Initiative Observational Study by Lowest and Highest Quintile Scores on 4 Diet Quality Indices, 1993–2010

Characteristic	Diet Quality Index															
	HEI[a]				AHEI[b]				aMED[c]				DASH[d]			
	Quintile 1		Quintile 5		Quintile 1		Quintile 5		Quintile 1		Quintile 5		Quintile 1		Quintile 5	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Total participants	12,761		12,761		12,761		12,761		11,685		15,708		14,330		14,576	
Deaths from any cause	1,292		1,061		1,296		1,027		1,263		1,211		1,400		1,181	
Deaths from cardiovascular disease	311		267		334		254		325		324		353		308	
Deaths from cancer	544		447		514		468		509		534		592		507	
Ethnicity																
Non-Hispanic white		77		88		79		87		80		88		73		91
Black		12		8		13		4		9		6		14		4
Hispanic		6		2		5		2		6		2		7		2
Other		5		4		3		6		5		4		6		3
College graduate		30		52		29		58		30		55		29		57
Married/living as married		60		65		61		65		61		66		62		62
Never smoker		48		53		53		46		51		51		49		53
Postmenopausal hormone therapy																
Never		44		36		44		36		43		36		43		37
Former		13		14		13		13		14		13		13		13
Current		42		50		42		51		43		51		43		50
Diabetes		14		9		14		9		13		9		14		8

Abbreviations: AHEI, Alternative Healthy Eating Index 2010; aMED, Alternate Mediterranean Diet Score; DASH, Dietary Approaches to Stop Hypertension; HEI, Healthy Eating Index 2010.

[a] From Guenther et al. (5).

[b] From Chiuve et al. (8).

[c] From Fung et al. (10).

[d] From Fung et al. (11).

analyses stratified by measured BMI (<25.0, 25.0–29.9, or ≥30.0) and measured waist circumference (≤88 cm or >88 cm), building on past research that demonstrated independent associations of overall and abdominal obesity with higher mortality risk in the WHI OS (28); we tested for interaction by BMI and waist circumference categories using Wald χ^2 tests.

All statistical tests were based on a priori hypotheses; therefore, no adjustment was performed for multiple testing. All statistical analyses were conducted using SAS, version 9.2, software (SAS Institute, Inc., Cary, North Carolina). All tests were 2-sided with statistical significance set at $P < 0.05$.

RESULTS

Across diet quality indices, compared with women with poor-quality diets (quintile 1), women with better-quality diets (quintile 5) were older, had lower BMI values, engaged in more physical activity, and were more likely to be college educated, non-Hispanic white, and current users of postmenopausal hormone replacement therapy; they were also less likely to have diabetes (Tables 2 and 3). Women who were lost to follow-up during the study ($n = 655$) had slightly lower diet quality scores than women with complete follow-up (data not shown). Univariate correlations between the 4 diet quality indices were fairly strong, ranging from 0.55 to 0.70 (all $P < 0.0001$), with the strongest correlation between HEI and DASH (data not shown).

Over a median 12.9 years of follow-up, 5,692 deaths occurred, including 1,483 from CVD and 2,384 from cancer. As shown in Table 4, in multivariate models, across indices, having a better-quality diet was associated with lower risks of death from all causes and CVD (all $P \leq 0.017$). A lower risk of cancer death was observed for women with higher HEI, aMED, and DASH scores (all $P \leq 0.001$), but not for those with higher AHEI scores ($P = 0.275$). Additional adjustment for hypertension and high cholesterol did not result in changes to the hazard ratios (data not shown). Models without BMI as a covariate yielded similar results (data not shown). As shown in Table 5, among women with BMI values of less than 25.0 or between 25.0 and 29.9, higher scores on all indices were associated with a lower risk of all-cause mortality (all $P \leq 0.022$), but among those with BMI values of 30 or more, only HEI was associated with all-cause mortality risk ($P = 0.023$).

Among women with BMI values less than 25.0, higher HEI and DASH scores were associated with a lower risk of CVD death (all $P \leq 0.038$). Among women with BMI values between 25.0 and 29.9, higher HEI, AHEI, and aMED scores were associated with a lower risk of CVD death (all $P \leq 0.047$). No scores were associated with CVD mortality risk among women with BMI values of 30.0 or higher.

Among women with BMI values less than 25.0 or between 25.0 and 29.9, higher HEI, aMED, and DASH scores, but not AHEI scores, were associated with a lower risk of cancer death (all $P \leq 0.032$) (Table 5). No scores were associated with cancer mortality risk among women with BMI values of 30 or higher.

As shown in Table 6, among women with a waist circumference of 88 cm or less, higher HEI, aMED, and DASH

Table 3. Additional Characteristics of 63,805 Participants in the Women's Health Initiative Observational Study By Lowest and Highest Quintile of Scores on 4 Diet Quality Indices, 1993–2010

Characteristic	Diet Quality Index							
	HEI[a]		AHEI[b]		aMED[c]		DASH[d]	
	Quintile 1, mean (SE)	Quintile 5, mean (SE)	Quintile 1, mean (SE)	Quintile 5, mean (SE)	Quintile 1, mean (SE)	Quintile 5, mean (SE)	Quintile 1, mean (SE)	Quintile 5, mean (SE)
Alcohol intake, g/day	5.7 (0.1)	5.2 (0.07	4.7 (0.1)	6.9 (0.1)	4.9 (0.1)	6.4 (0.1)	5.5 (0.1)	5.2 (0.1)
Age, years	61.9 (0.06)	64.2 (0.06)	62.4 (0.06)	63.2 (0.06)	62.8 (0.07)	63.0 (0.06)	62.0 (0.06)	63.7 (0.06)
Body mass index[e]	28.9 (0.06)	25.6 (0.04)	28.7 (0.06)	25.6 (0.04)	28.1 (0.06)	26.1 (0.04)	28.5 (0.05)	25.7 (0.04)
Energy intake, kcal/day	1,781.0 (6.6)	1,431.5 (4.1)	1,661.7 (5.7)	1,561.9 (4.8)	1,335.5 (4.8)	1,798.2 (4.7)	1,503.6 (5.0)	1,675.1 (4.6)
Index score	18–58[f]	76–95[f]	19–44[f]	63–94[f]	0–2[f]	6–9[f]	8–20[f]	28–37[f]
Physical activity, MET-hours/week	7.8 (0.1)	16.7 (0.1)	7.8 (0.1)	17.9 (0.1)	8.6 (0.1)	16.1 (0.1)	7.6 (0.1)	17.6 (0.1)

Abbreviations: AHEI, Alternative Healthy Eating Index 2010; aMED, Alternate Mediterranean Diet Score; DASH, Dietary Approaches to Stop Hypertension; HEI, Healthy Eating Index 2010; MET, metabolic equivalent unit; SE, standard error.

[a] From Guenther et al. (5).
[b] From Chiuve et al. (8).
[c] From Fung et al (10).
[d] From Fung et al. (11).
[e] Weight (kg)/height (m)^2.
[f] Values are expressed as a range.

Table 4. Multivariate Hazard Ratios for Mortality Risk by Quintile of Scores on Diet Quality Indices in the Women's Health Initiative Observational Study, 1993–2010

Quintile by Diet Quality Index	No. of Participants	Deaths From All Causes			CVD Deaths			Cancer Deaths		
		No. of Deaths	Multivariate HR	95% CI	No. of Deaths	Multivariate HR	95% CI	No. of Deaths	Multivariate HR	95% CI
HEI[a,b,c]										
Quintile 1	12,761	1,292	1.00	Referent	311	1.00	Referent	544	1.00	Referent
Quintile 2	12,761	1,192	0.93	0.86, 1.01	326	1.07	0.91, 1.25	478	0.88	0.78, 1.00
Quintile 3	12,761	1,047	0.82	0.75, 0.89	303	0.99	0.84, 1.17	417	0.76	0.67, 0.87
Quintile 4	12,761	1,100	0.84	0.77, 0.92	276	0.88	0.75, 1.05	498	0.89	0.78, 1.02
Quintile 5	12,761	1,061	0.76	0.70, 0.83	267	0.78	0.65, 0.93	447	0.77	0.68, 0.89
$P_{contrastQ5:Q1}$			<0.0001			0.006			0.0002	
AHEI[a,d]										
Quintile 1	12,761	1,296	1.00	Referent	334	1.00	Referent	514	1.00	Referent
Quintile 2	12,761	1,207	0.93	0.86, 1.01	334	0.99	0.85, 1.16	480	0.93	0.82, 1.05
Quintile 3	12,761	1,162	0.90	0.83, 0.98	312	0.94	0.80, 1.10	479	0.93	0.82, 1.06
Quintile 4	12,761	1,000	0.79	0.72, 0.86	249	0.77	0.65, 0.91	443	0.87	0.76, 0.99
Quintile 5	12,761	1,027	0.82	0.76, 0.90	254	0.81	0.68, 0.96	468	0.93	0.81, 1.06
$P_{contrastQ5:Q1}$			<0.0001			0.017			0.275	
aMED[a,e]										
Quintile 1	11,685	1,263	1.00	Referent	325	1.00	Referent	509	1.00	Referent
Quintile 2	11,416	1,056	0.87	0.80, 0.94	267	0.86	0.73, 1.01	428	0.87	0.76, 0.99
Quintile 3	12,919	1,142	0.84	0.77, 0.91	284	0.82	0.70, 0.97	485	0.88	0.77, 1.00
Quintile 4	12,077	1,020	0.80	0.73, 0.87	283	0.87	0.74, 1.03	428	0.83	0.73, 0.95
Quintile 5	15,708	1,211	0.74	0.68, 0.81	324	0.79	0.67, 0.94	534	0.80	0.70, 0.92
$P_{contrastQ5:Q1}$			<0.0001			0.006			0.001	
DASH[a,b,f]										
Quintile 1	14,330	1,400	1.00	Referent	353	1.00	Referent	592	1.00	Referent
Quintile 2	9,129	832	0.91	0.83, 0.99	210	0.91	0.77, 1.08	318	0.82	0.71, 0.94
Quintile 3	16,004	1,410	0.86	0.80, 0.93	370	0.89	0.77, 1.04	587	0.85	0.76, 0.96
Quintile 4	9,766	869	0.86	0.79, 0.94	242	0.93	0.79, 1.11	380	0.90	0.79, 1.03
Quintile 5	14,576	1,181	0.76	0.70, 0.83	308	0.76	0.65, 0.90	507	0.80	0.70, 0.91
$P_{contrastQ5:Q1}$			<0.0001			0.002			0.0006	

Abbreviations: AHEI, Alternative Healthy Eating Index 2010; aMED, Alternate Mediterranean Diet Score; CI, confidence interval; DASH, Dietary Approaches to Stop Hypertension; HEI, Healthy Eating Index 2010; HR, hazard ratio.

[a] Adjusted for age, energy intake, ethnicity, educational level, marital status, smoking, physical activity, postmenopausal hormone replacement therapy, body mass index (weight (kg)/height (m)^2), and diabetes status.

[b] Additionally adjusted for alcohol intake because alcohol was not included as a separate component in index.

[c] From Guenther et al. (5).

[d] From Chiuve et al. (8).

[e] From Fung et al. (10).

[f] From Fung et al. (11).

scores were associated with lower risks of all-cause, CVD-specific, and cancer-specific mortality; higher AHEI score was associated with a lower risk of all-cause mortality but not CVD or cancer death. Among women with a waist circumference of more than 88 cm, all scores were associated with a lower risk of all-cause mortality, but no scores were associated with CVD death, and only HEI score was associated with a lower risk of cancer death ($P = 0.011$). A total of 64% of women with a waist circumference greater than 88 cm had BMI values of 30.0 or more, and 88% of women with BMI values of 30.0 or more had a waist circumference greater than 88 cm (data not shown). Statistical interactions by BMI were observed for AHEI and DASH for all-cause and cancer death (all $P \leq 0.04$) and by waist circumference for aMED and all-cause mortality risk ($P = 0.009$).

DISCUSSION

This prospective study of approximately 64,000 postmenopausal women provided evidence that high scores on key

Table 5. Multivariate Hazard Ratios[a] for Mortality Risk Comparing the Highest Versus the Lowest Quintile of Scores on 4 Diet Quality Indices Stratified by Body Mass Index[b] Category Among 63,115 Women in the Women's Health Initiative Observational Study, 1993–2010

Cause of Death by Diet Quality Index	BMI <25 ($n = 26,551$)			BMI 25–29.9 ($n = 21,628$)			BMI ≥30 ($n = 14,936$)			$P_{interaction}$[c]
	HR	95% CI	*P* Value	HR	95% CI	*P* Value	HR	95% CI	*P* Value	
HEI[d]										
All causes	0.72	0.62, 0.82	<0.0001	0.84	0.73, 0.98	0.022	0.81	0.67, 0.97	0.023	0.369
CVD	0.74	0.56, 0.98	0.038	0.72	0.52, 1.00	0.047	0.87	0.61, 1.23	0.420	0.665
Cancer	0.79	0.64, 0.97	0.027	0.68	0.53, 0.86	0.001	0.90	0.68, 1.18	0.438	0.407
AHEI										
All causes	0.78	0.68, 0.90	0.0004	0.80	0.68, 0.92	0.003	0.97	0.82, 1.16	0.758	0.043
CVD	0.82	0.62, 1.09	0.172	0.70	0.51, 0.96	0.025	0.93	0.66, 1.30	0.661	0.674
Cancer	0.89	0.72, 1.10	0.283	0.82	0.65, 1.03	0.095	1.19	0.92, 1.55	0.194	0.044
aMED										
All causes	0.67	0.59, 0.77	<0.0001	0.74	0.64, 0.86	0.0001	0.86	0.73, 1.02	0.078	0.128
CVD	0.81	0.62, 1.07	0.138	0.60	0.44, 0.81	0.0008	0.99	0.73, 1.36	0.972	0.836
Cancer	0.73	0.59, 0.90	0.003	0.78	0.62, 0.98	0.032	0.98	0.75, 1.27	0.868	0.331
DASH[d]										
All causes	0.67	0.59, 0.77	<0.0001	0.80	0.69, 0.95	0.003	0.89	0.75, 1.05	0.156	0.002
CVD	0.71	0.54, 0.93	0.013	0.81	0.60, 1.08	0.148	0.75	0.54, 1.04	0.082	0.287
Cancer	0.69	0.56, 0.84	0.0002	0.73	0.58, 0.92	0.007	1.13	0.87, 1.46	0.374	0.001

Abbreviations: AHEI, Alternative Healthy Eating Index 2010; aMED, Alternate Mediterranean Diet Score; BMI, body mass index; CI, confidence interval; CVD, cardiovascular disease; DASH, Dietary Approaches to Stop Hypertension; HEI, Healthy Eating Index 2010; HR, hazard ratio.

[a] Adjusted for age, energy intake, ethnicity, educational level, marital status, smoking, physical activity, postmenopausal hormone replacement therapy, and diabetes.

[b] Weight (kg)/height (m)^2.

[c] *P* value for Wald χ^2 for interaction term at 8 df.

[d] Additionally adjusted for alcohol intake because alcohol was not included as a separate component in index.

diet quality indices were associated with an 18%–26% lower risk of death overall and from 2 of the most common diet-related chronic diseases—CVD and cancer. Our study is consistent with past research that has documented inverse associations between single a priori diet quality indices and all-cause mortality risk and CVD death (Mediterranean diet (29–31); HEI (32); and AHEI (33, 34)). In our study, AHEI score was not associated with cancer death, which is consistent with the results of 1 past study (33) but contrasts with those of another (34). The AHEI was designed to measure adherence to a high-quality diet predictive of major chronic disease risk (9); some of its components may be somewhat specific to CVD risk, which may explain its lack of robustness for predicting cancer mortality risk in our study. Our results are also consistent with all-cause mortality findings among populations with CVD (AHEI among 2,258 myocardial infarction patients (35); DASH among 3,215 postmenopausal heart failure patients (36)) and populations with cancer (HEI among 670 breast cancer survivors (22) and 2,317 breast cancer survivors (37); AHEI and DASH among 4,103 breast cancer survivors (38)).

This past literature is difficult to summarize because the indices and analytical methods varied from study to study. Most importantly, our findings build on recent results among older US adults reported by our DPMP collaborators (39); and, in tandem, the results from the DPMP show the robustness of these diet quality measures in predicting mortality risk in different populations. Because of its size, comprehensiveness, and standardized methodology, our study can inform those developing dietary guidelines for women of postmenopausal age of the potential survival benefit associated with consuming a diet in line with the indices explored in this paper.

To our knowledge, our study is the first to address the potential heterogeneity of the diet quality–mortality risk relationship by obesity status. We found that diet quality seems to be a weaker and less significant predictor of death at high levels of BMI. There are several potential explanations for this finding. First, it may be due to exposure misclassification and differential measurement error; having a high BMI is associated with underreporting of food intakes, and the foods most underreported are those that dietary guidelines advise populations to consume in moderation (e.g., high-fat, high-sugar, and high-calorie/low–nutrient-dense foods) (40). Alternatively, it is possible that once a person has a high BMI value, many aspects of beneficial diets that are captured in these indices are less likely to be inversely associated with mortality risk unless individuals also lose weight, because of the physiological impact of obesity. However, even if

Table 6. Multivariate Hazard Ratios[a] for Mortality Risk Comparing the Highest Versus the Lowest Quintile of Scores on 4 Diet Quality Indices Stratified by Waist Circumference Among 63,805 Women in the Women's Health Initiative Observational Study, 1993–2010

Cause of Death by Diet Quality Index	Waist Circumference ≤88 cm (n = 43,236)			Waist Circumference >88 cm (n = 20,569)			$P_{\text{interaction}}$[b]
	HR	95% CI	*P* Value	HR	95% CI	*P* Value	
HEI[c]							
All causes	0.74	0.66, 0.83	<0.0001	0.78	0.67, 0.90	0.0009	0.116
CVD	0.72	0.57, 0.91	0.006	0.85	0.64, 1.13	0.260	0.636
Cancer	0.79	0.67, 0.94	0.008	0.74	0.59, 0.93	0.011	0.213
AHEI							
All causes	0.83	0.75, 0.93	0.001	0.84	0.73, 0.97	0.020	0.237
CVD	0.81	0.64, 1.02	0.067	0.86	0.65, 1.13	0.285	0.895
Cancer	0.95	0.81, 1.13	0.585	0.92	0.73, 1.14	0.435	0.657
aMED							
All causes	0.72	0.64, 0.80	<0.0001	0.80	0.70, 0.92	0.002	0.009
CVD	0.73	0.58, 0.92	0.007	0.91	0.71, 1.18	0.488	0.427
Cancer	0.80	0.67, 0.94	0.008	0.82	0.66, 1.02	0.075	0.551
DASH[c]							
All causes	0.73	0.65, 0.81	<0.0001	0.86	0.75, 0.98	0.029	0.121
CVD	0.74	0.59, 0.92	0.008	0.86	0.67, 1.11	0.151	0.539
Cancer	0.73	0.62, 0.86	0.0001	0.93	0.75, 1.16	0.523	0.078

Abbreviations: AHEI, Alternative Healthy Eating Index 2010; aMED, Alternate Mediterranean Diet Score; CI, confidence interval; CVD, cardiovascular disease; DASH, Dietary Approaches to Stop Hypertension; HEI, Healthy Eating Index 2010; HR, hazard ratio.

[a] Adjusted for age, energy intake, ethnicity, educational level, marital status, smoking, physical activity, postmenopausal hormone replacement therapy, and diabetes.

[b] *P* value for Wald χ^2 for interaction term at 4 df.

[c] Additionally adjusted for alcohol intake because alcohol was not included as a separate component in index.

diet quality does not have a direct survival benefit for obese women, consuming a high-quality diet has been shown to be important for weight loss and maintenance in overweight and obese adults (41), and lower BMI values at midlife have been associated with a lower risk of death (42).

Among women with a waist circumference greater than 88 cm, associations between indices and CVD and cancer mortality risk were null, with the exception of HEI being inversely associated with cancer death. This finding seems to mirror the null cause-specific findings observed in this study among women with BMI values of 30.0 or more. However, for all-cause mortality, our conclusions about diet quality's predictive value across obesity levels differed on the basis of whether we defined obesity using BMI (overall obesity) or waist circumference (abdominal obesity). Although the directions of association were the same, the magnitude of association was stronger and more likely to be statistically significant among those with a high waist circumference than among those with a high BMI value. One possible reason is that waist circumference may be a more direct measure of body composition because a higher waist circumference indicates a greater extent of abdominal obesity, which is more tightly linked to metabolic dysfunction than BMI alone. Abdominal obesity is known to be associated with abnormal production of inflammatory and metabolic cytokines that are responsive to dietary manipulation (43). However, considering that only some of the interaction terms for BMI and waist circumference were significant, and that interpretation of the interaction terms is complex, replication of these findings in future research is needed.

Overall, the diet quality scores that we examined in this paper showed similar relationships with mortality risk, and they share some commonalities. All scores emphasize intakes of fruit, vegetables, whole grains, and plants or plant-based proteins. All scores except DASH emphasize consumption of polyunsaturated and monounsaturated fats over saturated fats. All except aMED include a sodium component because of its importance in lowering blood pressure and preventing coronary heart disease and stroke (44). All indices except HEI stress nut consumption. aMED and AHEI emphasize moderate consumption of alcohol because of its association with lower CVD risk (45), as well as low intake of red and processed meat, which is a risk factor for certain cancers (46–48). HEI and aMED include a seafood component. The comprehensive results presented here show that, although these indices were developed for slightly different purposes, include some different components, and vary in their definitions of optimal diet quality and scoring, they are also all capturing the essential elements of a healthy diet. This was evidenced by the fairly strong correlations between scores and the strikingly consistent magnitudes of hazard ratios when comparing scores in the highest and lowest quintiles across the indices, except for AHEI and cancer death.

Advantages of this study include the use of the multidimensional diet quality indices that capture the potentially synergistic nature of multiple important dietary components (49) and permit comparisons among study populations. Further strengths include objectively measured height, weight, and waist circumference, large sample size, the prospective nature of evaluations, long-term mortality follow-up, and central adjudication of deaths. Additionally, the WHI OS had high-quality data on covariates, allowing us to make simultaneous adjustments for factors known to alter mortality risk and to conduct a thorough analysis.

Study limitations include measurement error inherent to the FFQ (50) and to other self-reported measures of health behaviors, like physical activity (51). Measurement error is most keenly recognized for energy (52), but less is known about the extent and severity of measurement error for many of the dietary measures presented in this report. Because there are no quantitative/recovery biomarkers for these dietary components, it is not possible to infer that the same type of measurement error exists for these components as it does for energy, and future research is needed in this area. Additionally, although we had detailed data allowing us to carefully control for the major confounders and to show that associations were unlikely to be artifacts of reverse causation, given the observational nature of this study, it remains possible that those who chose a better-quality diet lived longer for reasons that we did not examine.

Overall, within this cohort of postmenopausal women, associations of diet quality and mortality outcomes were consistent, of similar magnitudes, and highly significant, regardless of the index of choice, with the exception of AHEI and death from cancer. Most importantly, this large study of nearly 64,000 women and 6,000 deaths provides needed data on diet quality and health—an important public health topic currently being considered in examining the scientific basis for the 2015 Dietary Guidelines for Americans. Our study suggests that postmenopausal women who consume a diet consistent with a priori–specified diet quality indices such as HEI, AHEI, aMED, and DASH may have a lower risk of death from chronic diseases.

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Author affiliations: Applied Research Program, Division of Cancer Control and Population Sciences, National Cancer Institute, Bethesda, Maryland (Stephanie M. George, Rachel Ballard-Barbash, Jill Reedy, Amy F. Subar); Department of Medicine, Brigham and Women's Hospital, Harvard Medical School (JoAnn E. Manson); Division of Preventive Medicine, School of Medicine, University of Alabama at Birmingham, Birmingham, Alabama (James M. Shikany); Division of Public Health Sciences, Fred Hutchinson Cancer Research Center, Seattle, Washington (Lesley F. Tinker, Marian L. Neuhouser); and Wake Forest School of Medicine, Division of Public Health Sciences, Winston-Salem, North Carolina (Mara Vitolins).

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