Original Contribution

Does Season of Reported Dietary Intake Influence Diet Quality? Analysis From the Women's Health Initiative

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We evaluated the role of seasonality in self-reported diet quality among postmenopausal women participating in the Women's Health Initiative (WHI). A total of 156,911 women completed a food frequency questionnaire (FFQ) at enrollment (1993–1998). FFQ responses reflected intake over the prior 3-month period, and seasons were defined as spring (March–May), summer (June–August), fall (September–November), and winter (December–February). FFQ data were used to calculate the Alternate Healthy Eating Index (AHEI), a measure of diet quality that has a score range of 2.5–87.5, with higher scores representing better diet quality. In multivariable linear regression models using winter as the reference season, AHEI scores were higher in spring, summer, and fall (all P values < 0.05); although significant, the variance was minimal (mean AHEI score: winter, 41.7 (standard deviation, 11.3); summer, 42.2 (standard deviation, 11.3)). Applying these findings to hypothesis-driven association analysis of diet quality and its relationship with chronic disease risk (cardiovascular disease) showed that controlling for season had no effect on the estimated hazard ratios. Although significant differences in diet quality across seasons can be detected in this population of US postmenopausal women, these differences are not substantial enough to warrant consideration in association studies of diet quality.

dietary measurement; diet quality; season; women's health

Abbreviations: AHEI, Alternate Healthy Eating Index; CVD, cardiovascular disease; FFQ, food frequency questionnaire; SD, standard deviation; WHI, Women's Health Initiative; WHI-OS, Women's Health Initiative Observational Study.

In the United States and most of the world, there are established, discrete growing seasons for food. However, with the dramatic increase in the commercialization of food production, largely in the developed world, it is unknown whether season influences overall diet quality. Currently, no consensus definition for seasonality exists; however, seasonality is generally thought to reference any regular pattern or variation that is correlated with the seasons. In defining food seasonality, the definition may vary according to where the food is produced as well as where the food is consumed (1). Season-specific weather conditions may influence the availability of crops (2), particularly in situations wherein imports from distant areas are limited or restricted. Importantly, the consumption of “out-of-season” produce has become increasingly possible as the global food trade has increased and as the utilization of agroindustrial techniques has filled seasonal gaps

in access. Yet, much of the fresh food produced, sold, and purchased by households in any country remains somewhat subject to seasonal changes (3, 4).

Despite awareness of a potential variance in food availability and choices by season, evidence that season is associated with food intake in the general population is somewhat limited. Seasonal differences in dietary intake have been reported in female young adults residing in Spain (5). Similarly, seasonal variance in intake was reported using diet history questionnaire data generated from adult males and females in Japan (6) and in relation to energy intake in a year-long dietary analysis of US adults conducted by the US Department of Agriculture (7). Additionally, a study of blood folate concentrations in adults showed higher concentrations in samples collected during the summer, largely as a result of higher dietary folate intake as compared with winter and early spring (8). In contrast,

Bernstein et al. (9) found that residents of the metropolitan Washington, DC, area did not exhibit seasonal variation in dietary intake. An analysis of National Health Interview Survey diet data from 1989 suggested that intake differed across seasons by more than 5% for 22 of 59 food items but that differences were small and did not significantly affect population estimates (10). Of interest is a report describing change in the gut microbiome, a more objective measure of dietary patterns, by season, which supports the hypothesis that season may contribute to variance in diet quality (11).

Diet quality measures—for example, the Alternate Healthy Eating Index (AHEI)—align reported intakes of vegetables, fruit, fiber, saturated fat, nuts, and alcohol with recommended dietary guidelines developed to reduce chronic disease risk (12). Such diet quality scores have been associated with risk of several chronic diseases (13), with lower scores being associated with increased risk of cancer (14, 15), cardiovascular disease (CVD) (16), and obesity (17). Diet quality, based on component food groups and known seasonal variability in costs and availability of composite scored food groups, may be affected by the season in which diet is reported. Whether the season of the year in which dietary intake data are collected influences diet quality scores is unknown (18).

While data representative of usual food consumption are necessary in order to establish accurate conclusions regarding the relationship between diet and chronic disease risk, seasonality is often overlooked as a possible determinant of diet quality in adults (19). Here we present results from an analysis of a large sample of postmenopausal women enrolled in the Women's Health Initiative (WHI), representing wide regional variance across the United States (West, Midwest, South, and Northeast), to evaluate the role of seasonality in dietary intake and diet quality. We hypothesized that seasonality would be associated with diet quality (as measured by the AHEI) in our sample of postmenopausal women, such that AHEI scores would be higher in the summer months. Because fruit and vegetable intake are more likely to show variable intake by season (3, 4), we sought to specifically address this exposure in relation to seasonality and dietary quality. To robustly evaluate these exposures, we objectively estimated fruit and vegetable consumption, via serum carotenoid levels, in a subsample analysis.

An earlier report from the WHI suggested that an inverse association between AHEI and CVD risk existed (20). To test this hypothesis within an existing epidemiologic analysis, we evaluated effect modification (if any) of the relationship between AHEI and CVD risk by seasonality, as positive findings would have important implications for studying diet-disease associations.

METHODS

Study sample

From 1993 to 1998, postmenopausal women 50–79 years of age were recruited into clinical trials or an observational study ($n = 161,808$) of the WHI, as described previously (21–23). When the first phase of the WHI ended (2004–2005), participants were invited to join WHI Extension 1 (2005–2010) and later WHI Extension 2 (2010–2015). This analysis draws on

the WHI Observational Study (WHI-OS). The analytical sample was restricted to participants who completed a food frequency questionnaire (FFQ) at baseline and reported a plausible energy intake (600–5,000 kcal/day), yielding a total analytical sample of 90,009 women.

Dietary assessment and seasonality

Assignment of intake by season was based upon month of completion of the baseline FFQ developed and validated for the WHI (24). Specifically, women were asked to complete the questionnaire reflecting on the prior 3 months of intake. A total of 122 composite and single-food line items asked about consumption frequency and portion size; 19 adjustment questions were related to fat intake/type; and 4 summary questions asked about usual intakes of fruits and vegetables and added fats, used for comparison with the line-item information.

Seasonality was defined using 3-month intervals of food frequency data. Food frequency data collected from March to May were assigned as spring, those collected from June to August were assigned as summer, those collected during September–November were assigned as fall, and those collected in December–February were assigned as winter. Thus, month of FFQ completion served as a surrogate for seasonality. Notably, regardless of the referent period that is assigned for FFQ response (e.g., 3 months, 1 month, etc.), literature suggests that study participants frequently report more recent/current intake (25–27).

Diet quality was measured according to the AHEI-2010 scoring criteria (see Web Table 1, available at <https://academic.oup.com/aje>). The AHEI-2010 is designed to quantify compliance with key diet-related recommendations of the 2010 Dietary Guidelines for Americans (28). Using the WHI FFQ, we calculated AHEI score by summing all components to obtain a total AHEI score ranging from 2.5 (lowest quality) to 87.5 (highest quality).

Serum carotenoids

Serum carotenoids were measured in a random 6% subsample of WHI women ($n = 1,013$). Briefly, carotenoid data were included if the date of blood specimen collection fell within 28 days of the date of FFQ completion, limiting this analysis to 506 women. Serum carotenoid levels were measured by high-performance liquid chromatography. Lutein, zeaxanthin, and lycopene were detected at 476 nm and α -carotene and β -carotene at 452 nm; all concentrations were adjusted for serum cholesterol. These methods have been previously described (29, 30).

Statistical analysis

Mean AHEI scores and their individual components (food groups) were compared across the months of FFQ completion using analysis of variance. Baseline characteristics of WHI participants were compared across seasons of FFQ completion using analysis of variance for continuous variables and χ^2 tests for categorical variables. Linear regression models were applied to test the association between month of FFQ completion (season) and AHEI score.

Regression models adjusted for confounding by age, race/ethnicity, geographic region, latitude, income, education, employment status, energy intake (log-transformed), and physical activity, using a *P* value of 0.10 to designate significance. We conducted a sensitivity analysis restricting the analytical sample to women who completed the FFQs in the last month of each season (i.e., February, May, August, and November), to reflect the responses for the prior 3 months of the respective season. Correlations between geographic region and latitude were also explored using Pearson's correlation coefficient. In a subset analysis of women who had serum carotenoid measurements, we performed a 1-way analysis of variance test to evaluate the association between total serum carotenoid levels and month of FFQ completion.

Additionally, we investigated seasonality as an effect modifier using a previously published analysis by Belin et al. (20). In that paper, the authors reported a significant association between higher AHEI score and lower CVD risk, suggesting a 33% lower risk of incident CVD in WHI-OS women who reported higher AHEI scores in adjusted models (20). We replicated this analysis with an updated data set (longer total follow-up) and further adjusted for seasonality. In addition to CVD risk, we also evaluated potential interaction between seasonality and age, body mass index (weight (kg)/height (m)²) category, smoking status, alcohol intake, race/ethnicity, region, latitude, and neighborhood socioeconomic status. Likelihood ratio tests were applied to determine whether there was a

difference in log-likelihoods from models with and without interaction terms.

RESULTS

Diet quality had minimal, but statistically significant, variance over the course of the year when assessing AHEI by month of FFQ completion (Table 1). The lowest mean AHEI score was 41.6 (for January), and the highest score was 42.4 (for August) (*P* < 0.001). The AHEI component (food groups) distribution across seasons (Web Figure 1) suggested little variance related to the time of year at which the FFQ was completed. Although self-reported fruit and vegetable intake did not vary by season, the subset analysis of serum total carotenoid concentrations measured within 28 days of FFQ completion showed higher mean carotenoid concentrations in the summer (1.31 (standard deviation (SD), 0.61) $\mu\text{mol/L}$; range, 0.16–3.41 $\mu\text{mol/L}$) versus the winter (1.11 (SD, 0.57) $\mu\text{mol/L}$; range, 0.04–5.07 $\mu\text{mol/L}$) (*t* test *P* = 0.015; Table 1).

Women completing the FFQ in the fall and winter were more likely to be older, of black or Hispanic origin, and not currently employed and to report lower family income as compared with women completing the FFQ in the spring or summer months (Table 2). The magnitude of the correlation between geographic region and latitude was moderate (Pearson's *r* = −0.3032), so neither term was removed from the

Table 1. Mean Alternate Healthy Eating Index Score and Serum Total Carotenoid Concentration by Month and Season of Food Frequency Questionnaire Completion at Enrollment, Women's Health Initiative, 1993–1998

Season and Month of FFQ Completion	No. of Women (n = 89,979) ^a	%	Mean (SD) AHEI Score ^b	No. in Carotenoid Subsample ^c (n = 506)	Mean (SD) Serum Carotenoid Concentration, $\mu\text{mol/L}$ ^d
Winter	20,788	23.10	41.7 (11.3)	155	1.11 (0.6)
December	5,356	5.95	41.7 (11.4)	35	1.21 (0.5)
January	7,858	8.73	41.6 (11.2)	75	1.11 (0.6)
February	7,574	8.42	41.7 (11.2)	45	1.04 (0.6)
Spring	23,234	25.80	42.1 (11.2)	74	1.23 (0.6)
March	7,782	8.65	42.0 (11.2)	42	1.31 (0.7)
April	7,635	8.48	42.2 (11.1)	25	1.17 (0.6)
May	7,817	8.69	42.1 (11.3)	7	0.94 (0.3)
Summer	25,089	27.90	42.2 (11.3)	75	1.31 (0.6)
June	8,516	9.46	42.2 (11.3)	10	1.21 (0.5)
July	8,989	9.99	42.0 (11.2)	26	1.25 (0.5)
August	7,584	8.43	42.4 (11.5)	39	1.38 (0.7)
Fall	20,868	23.20	41.8 (11.4)	202	1.29 (0.6)
September	6,922	7.70	41.8 (11.4)	62	1.45 (0.7)
October	7,084	7.87	41.9 (11.4)	70	1.30 (0.7)
November	6,862	7.63	41.8 (11.3)	70	1.14 (0.5)

Abbreviations: AHEI, Alternate Healthy Eating Index; FFQ, food frequency questionnaire; SD, standard deviation.

^a Data on AHEI score were missing for 30 women.

^b *P* < 0.0001 for 1-way analysis of variance, season, and AHEI score.

^c Women who had blood drawn within 28 days of FFQ completion.

^d *P* = 0.0335 for 1-way analysis of variance, season, and total carotenoid concentration.

Table 2. Characteristics of Participants by Season of Food Frequency Questionnaire Completion at Enrollment, Women's Health Initiative, 1993–1998

Characteristic	Season						P Value ^a		
	Winter (n = 20,791; 23.1%)		Spring (n = 23,243; 25.8%)		Summer (n = 25,096; 27.9%)			Fall (n = 20,879; 23.2%)	
	Mean (SD)	%	Mean (SD)	%	Mean (SD)	%		Mean (SD)	%
Age, years	63.9 (7.3)		63.3 (7.4)		63.4 (7.4)		63.9 (7.3)		<0.001
Race/ethnicity									<0.001
Non-Hispanic white	83.4		84.5		85.0		84.0		
Black	8.0		7.8		7.1		7.3		
Hispanic	3.4		3.4		3.7		3.9		
Asian	3.3		2.5		2.5		3.0		
Other/unknown	1.9		1.9		1.7		1.8		
Region									0.010
Northeast	23.2		22.4		22.4		23.6		
South	25.8		26.0		26.1		24.8		
Midwest	22.2		22.3		22.0		22.3		
West	28.8		29.4		29.5		29.2		
Latitude									<0.001
Southern (<35°N)	32.5		31.1		31.8		31.0		
Middle (35°–40°N)	25.5		27.6		29.4		27.7		
Northern (>40°N)	42.0		41.3		38.9		41.3		
Annual income									0.027
≤\$34,999	37.7		37.1		37.5		38.6		
\$35,000–\$74,999	39.3		39.3		39.6		39.1		
≥\$75,000	23.1		23.6		22.9		22.3		
Education									<0.001
High school or less	21.3		20.4		20.5		21.7		
Some college	36.2		36.8		36.0		36.8		
College graduation or more	42.5		42.8		43.5		41.6		
Currently employed	34.9		36.4		37.3		34.2		<0.001
Neighborhood SES	76.0 (8.6)		76.1 (8.5)		76.2 (8.3)		76.0 (8.4)		0.082
Physical activity (MET-hours/week)	13.4 (14.1)		14.1 (14.5)		13.9 (13.4)		13.7 (14.4)		<0.001
Body mass index ^b	27.3 (5.8)		27.2 (5.8)		27.3 (6.0)		27.2 (5.8)		0.097
Current smoker	12.5		12.2		12.3		13.2		0.112

Abbreviations: MET, metabolic equivalent of task; SD, standard deviation; SES, socioeconomic status.

^a P values were calculated using analysis of variance for continuous variables and χ^2 tests for categorical variables.^b Weight (kg)/height (m)².

final model. Neither body mass index nor smoking status was associated with season of FFQ completion.

In age-adjusted models with winter as the referent season, AHEI score was similar in fall but significantly higher in spring and summer (Table 3). After multivariate adjustment, AHEI scores were significantly higher in all 3 seasons than AHEI score in winter. The score was highest in summer (0.65 points higher than in winter; $P < 0.001$), followed by spring (0.46 points higher than in winter; $P < 0.001$) and fall (0.28 points higher than in winter; $P = 0.007$) (Table 3). Results demonstrated similar associations in a sensitivity analysis in which diet data were restricted to FFQs completed

during the final month of each 3-month season (results not shown).

Finally, we replicated a previously reported association between AHEI and incident CVD (Table 4, models 1 and 2) and further adjusted the model for seasonality (Table 4, model 3). The protective role of diet quality in relation to CVD risk in this sample of postmenopausal women was evident regardless of adjustment for seasonality. In fact, the hazard ratios and 95% confidence intervals were identical to the hundredths place before and after adjustment for seasonality. Likelihood ratio tests showed no effect of statistical interaction between seasonality and AHEI score on CVD risk ($P = 0.877$)

Table 3. Association Between Season and Baseline Diet Quality (Measured by Alternate Healthy Eating Index Score) in Linear Regression Models, Women's Health Initiative, 1993–1998

Season	Age-Adjusted		Multivariate ^a	
	β	P Value	β	P Value
Winter	0	Referent	0	Referent
Spring	0.48	<0.001	0.46	<0.001
Summer	0.56	<0.001	0.65	<0.001
Fall	0.17	0.120	0.28	0.007

^a Results were adjusted for age, race/ethnicity, region, latitude, income, education, employment, energy intake (log-transformed), and physical activity.

or of interaction between seasonality and the previously mentioned covariates on AHEI scores.

DISCUSSION

This analysis of data from the WHI-OS, a large cohort study of postmenopausal women, revealed statistically significant, albeit minimal, differences in AHEI score over seasons of FFQ data collection. Overall, the individual components of the AHEI appeared to remain stable across the seasons. One potential explanation for this is the habitual nature of eating behaviors among US adults, which may reflect the relative seasonal stability in the variety of the US food supply (31). For example, this analysis suggests that women who report consuming adequate amounts of vegetables in the summer are likely to report consuming adequate (the same) amounts of vegetables in the winter, but perhaps substituting the types of vegetables consumed in the summer for vegetables more readily available in the winter season (e.g., summer squash for winter squash).

The concept of seasonal variation in dietary intake has received limited attention in the literature (32), with inconsistent findings.

Several factors have been hypothesized to potentially influence dietary choices over the seasons, including the availability and cost of seasonal food, food distribution, and the sustainability of the local and national food supply (1), as well as variance in the types of foods provided by markets, restaurants, and/or mobile vendors (33). Notably, the WHI women overall reported higher-than-median economic status on the basis of neighborhood socioeconomic status.

In our subsample of 506 women, with available biomarkers of dietary fruit and vegetable intake for more rigorous assessment, the results suggested a significantly higher serum total carotenoid concentration (collected within 28 days of FFQ completion) during the summer as compared with the winter, despite no difference in self-reported fruit and vegetable intake. These findings suggest reduced measurement precision of dietary intake due to self-reporting bias (34). Importantly, the difference in serum total carotenoid concentrations, while statistically significant, appears modest in relation to biological significance: 1.31 (SD, 0.6) $\mu\text{mol/L}$ and 1.11 (SD, 0.6) $\mu\text{mol/L}$ in summer and winter, respectively. Our results also suggest potential differences in fruit and vegetable intake that are not captured by self-report but are evident in the variance of objective measurements of total carotenoid concentrations by season. Several factors may influence seasonal differences in fruit and vegetable intake, including environmental awareness and climate. Intake of fruit and vegetables is among the more seasonable of food choices. Consuming locally produced fruits and vegetables is a mainstay of a sustainable food plan (1). Beyond fruit and vegetables, consumption of cold foods (e.g., salads, fresh fruit) is likely to be higher in the summer (warmer) months, whereas consumption of warm foods (e.g., soups, stews) may be greater in the winter (colder) months, and these food choices may or may not influence diet quality (35).

For humans, the influence of seasonality begins with food production. The vast majority of plant species, as well as many species of animals raised for human consumption, are subject to an “agricultural calendar” imposed by the succession of the seasons. Eating behaviors may vary by season (4). The availability of food provided by the rhythm of the

Table 4. Association Between Baseline Diet Quality (Measured by Alternate Healthy Eating Index Score) and Cardiovascular Disease in Cox Proportional Hazards Regression Models, Women's Health Initiative, 1993–2015

Quintile of AHEI Score	No. of CVD Events (n = 6,158)	%	Model 1 ^a		Model 2 ^b		Model 3 ^c	
			HR	95% CI	HR	95% CI	HR	95% CI
1 (<32.129)	1,443	10.20	1.00	Referent	1.00	Referent	1.00	Referent
2 (32.129–38.841)	1,334	9.41	0.86	0.80, 0.92	0.94	0.84, 1.05	0.94	0.84, 1.05
3 (38.842–44.698)	1,212	8.55	0.75	0.69, 0.81	0.88	0.78, 0.98	0.88	0.78, 0.98
4 (44.699–51.701)	1,176	8.30	0.71	0.66, 0.77	0.83	0.74, 0.94	0.83	0.74, 0.94
5 (>51.701)	993	7.00	0.59	0.54, 0.63	0.84	0.73, 0.96	0.84	0.73, 0.96

Abbreviations: AHEI, Alternate Healthy Eating Index; CI, confidence interval; CVD, cardiovascular disease; HR, hazard ratio.

^a Results were adjusted for age and race/ethnicity.

^b Results were further adjusted for education (high school or less; some college; or college graduation or more), physical activity, energy intake (log-transformed), body mass index (weight (kg)/height (m)²), smoking status (never, past, or current smoking), diabetes medication (self-reported use of pills or receipt of insulin shots), ever use of pills for hypertension, and ever use of pills for high cholesterol.

^c Results were further adjusted for season.

seasons and associated changes in weather have conditioned and influenced human food consumption, perhaps limiting consumption of fresh food to those in season only at harvest times (2). Using the traditional methods of food preservation, preserved food was consumed when fresh food was not available or in the presence of reduced availability of other foods (36). Vast evidence suggests that total daily energy intake does not vary by season (10, 32), particularly for macronutrients such as protein (37) and carbohydrates (38). However, there is a small body of literature which suggests that intake does vary by season (32, 37, 39). Noteworthy is the fact that these conflicting studies reflect intakes reported more than 2 decades ago, prior to globalization of the food supply (40).

Even beyond seasons, there is some evidence that energy intake may vary during the holiday-centric winter season. In one US study, weight gain was reported during the 6-week winter period from Thanksgiving to New Year's Day (41). Notably, the reported weight gain was greater in persons who were overweight or obese, suggesting that holiday weight gain may be more a manifestation of obesogenic behaviors in response to the holiday food environment than of changes in food availability resulting from seasonal agricultural patterns (41). Our results would support this latter explanation in that we did not observe a difference between the winter (holiday) season and other seasons in terms of food-group intake. Our data did not include frequent body weight assessments, and thus we were unable to evaluate change in weight relative to self-reported food intake by season, and measurement error in energy intake further adds to the complexity of accurate interpretation (34).

Relevant to nutritional epidemiology are the findings from our analysis of seasonal moderation of the relationship between overall diet quality (AHEI) and CVD risk. Here we demonstrate that controlling for season in multivariate analysis has no impact on overall CVD risk estimates. These findings are important because they suggest that timing of dietary data collection in US epidemiologic cohorts may not require standardization by season or month of the year if the exposure in question is overall diet quality.

Limitations of this study include measurement imprecision associated with the self-reporting bias in FFQs and in estimating seasonality. However, adjusting for energy intake somewhat minimizes measurement error associated with self-reported FFQ intake (42). Using FFQ data, we did not know whether carotenoids were consumed with dietary fat—a factor that would enhance absorption and may differ seasonally. The difference in timing of the FFQ relative to the blood draw for measurement of total carotenoid levels ranged from –55 days to 999 days, with a median of 27 days. Serum carotenoids have a half-life of 26–76 days, with changes in individual carotenoid concentrations being strongly correlated (43). These findings may not be generalizable, given that WHI participants are limited to US postmenopausal women with higher income and educational status. The average adjusted AHEI score in our sample (42.0, 95% confidence interval: 41.9, 42.1) was similar to, albeit slightly higher than, that in the more diverse National Health and Nutrition Examination Survey population of older women in 1999–2000 (39.4, 95% confidence interval: 38.6, 40.1) (44). There were no data available with respect to whether foods consumed were local or imported, the location

where food was purchased, or region of food growth and distribution (urban vs. rural).

This robust analysis of a large, diverse sample of postmenopausal women provided strong evidence that season is not a confounder when analyzing diet quality among US women. Future studies may consider the seasonality of other dietary intake exposures, such as individual nutrients and environmental contaminants.

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