The 2018 World Cancer Research Fund/American Institute for Cancer Research Score and Cancer Risk: A Longitudinal Analysis in the NIH-AARP Diet and Health Study

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ABSTRACT

Background: We examined associations between adherence to the 2018 World Cancer Research Fund/American Institute for Cancer Research (WCRF/AICR) Cancer Prevention Recommendations using the standardized 2018 WCRF/AICR Score and cancer risk among older U.S. adults.

Methods: Participants included 215,102 adults in the NIH-AARP Diet and Health Study followed between 2004 and 2011 (mean 7.0 person-years). Scores (range: 0–7 points) were calculated from self-reported weight, physical activity, and diet and alcohol intake measures. Outcomes included 17 cancers reviewed by WCRF/AICR (cases: male $n = 11{,}066$; female $n = 8{,}865$) and top three U.S. cancers in males (total $n = 4{,}658$; lung $n = 2{,}211$; prostate $n = 920$; colorectal $n = 1{,}527$) and females (total $n = 5{,}957$; lung $n = 1{,}475$; post-menopausal breast $n = 3{,}546$; colorectal $n = 936$). Cox proportional hazard ratios (HRs) were estimated for score and cancer risk associations, stratifying by sex and smoking status.

Results: Each one-point score increase was associated with 6% to 13% reduced cancer risk across combined outcomes, except for male never smokers' risk for top three cancers and male current smokers' risk for both combined cancer outcomes. Higher scores were associated with decreased lung cancer risk only among male former smokers (HR, 0.84; 95% CI, 0.79–0.89) and female current smokers (HR, 0.89; 95% CI, 0.82–0.96). Higher scores were associated with 7% to 19% decreased breast cancer risk across smoking strata and 10% to 14% decreased colorectal cancer risk among male and female never and former smokers.

Conclusions: Greater recommendations adherence was associated with reduced cancer risk.

Impact: Findings emphasize the importance of considering combined contributions of multiple lifestyle factors for cancer prevention among older adults and the potential modifying role of smoking history.

Introduction

It is estimated that 40% of U.S. adults will be diagnosed with cancer during their lifetimes (1) and approximately 1.9 million new cancer cases are expected in 2021 (2). The three most commonly diagnosed types of cancer in men (prostate, lung, colorectal) and women (breast, lung, colorectal) account for approximately half of all new diagnoses (2). However, approximately 30% to 50% of all cancers could be prevented by making improvements to modifiable risk factors, including cigarette smoking, body weight, physical activity, dietary intake, and alcohol consumption (3, 4). Addressing cancer risk among older adults is a particular priority since the overall U.S. population is aging and age is the strongest nonmodifiable cancer risk factor.

In 2018, the World Cancer Research Fund (WCRF) and American Institute for Cancer Research (AICR) published their Third Expert Report on *Diet, Nutrition, Physical Activity, and Cancer: A Global Perspective* (3, 5). The report included 10 evidence-based Cancer Prevention Recommendations focused on modifiable lifestyle factors that impact cancer risk. Prior to the Third Expert Report, a substantial body of research had examined adherence to the 2007 WCRF/AICR Cancer Prevention Recommendations from their Second Expert Report (6). This research found adherence to recommendations was associated with a reduced risk of breast cancer, colorectal cancer, and lung cancer, although scores developed in these studies were heterogeneous and not directly comparable (7). Consequently, the 2018 WCRF/AICR Score was developed as a standardized scoring system to assess adherence to eight of the 10 WCRF/AICR Cancer Prevention Recommendations published in 2018, including body weight, physical activity, dietary intake, alcohol consumption, and breastfeeding (8, 9). The score allows researchers to examine multiple aggregated lifestyle factors in relation to cancer risk and health outcomes.

An emerging body of research has examined the association between adherence to the 2018 WCRF/AICR Cancer Prevention Recommendations and cancer risk (10–19), of which the majority of studies used the standardized 2018 WCRF/AICR Score (10, 11, 13–15, 18, 19). Most studies focused on risk of specific cancers including breast (11, 14, 15), colorectal (12, 16, 17), prostate (13), chronic lymphocytic leukemia (18), and pancreatic cancers (19), and most were conducted outside of the United States (10–15, 18). Therefore, studies are needed to examine how adherence to the 2018 WCRF/AICR Cancer Prevention Recommendations (3, 5) impacts overall cancer risk

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in the United States and particularly in older populations. Use of the standardized scoring system can support comparisons across future studies.

The objective of this study was to examine if adherence to the 2018 WCRF/AICR Cancer Prevention Recommendations using the standardized 2018 WCRF/AICR Score was associated with cancer risk among older adults in the NIH-AARP (formally known as the American Association of Retired Persons) Diet and Health Study. Given the strong evidence that cigarette smoking is a major cancer risk factor (3, 20, 21), we stratified the analyses by smoking status (never, former, or current smoker) to examine the potential modifying role of smoking history. Additional analyses explored associations between components of the 2018 WCRF/AICR Score and cancer risk.

Materials and Methods

Study population

The NIH-AARP Diet and Health Study was a prospective cohort study designed to better understand the relationship between diet and health. Details on participant recruitment and study design are available elsewhere (22). As described in a previous 2018 WCRF/AICR Score analysis, (23) AARP members aged 50–71 years who were residents of one of six states (California, Florida, Louisiana, New Jersey, North Carolina, Pennsylvania) or two metropolitan areas (Atlanta, Georgia and Detroit, Michigan) were contacted in 1995–1996 to participate via mailed baseline questionnaires. These questionnaires completed by respondents (n = 566,398) collected demographic, diet, and lifestyle characteristics data. The Risk Factor Questionnaire (1996–1997) and Follow-up Questionnaire (2004) collected additional information on lifestyle and reproductive factors and physical activity, respectively. Participants were followed through December 2011. The Special Studies Institutional Review Board of the National Cancer Institute approved the NIH-AARP Diet and Health Study.

Similar to our previous study (23), we excluded study participants from the current analysis if their questionnaires were completed by proxy (n = 15,760), they reported a previous history of cancer (n = 51,346), or their cancer deaths were not registry-confirmed (i.e., not just from the National Death Index, n = 4,268). We also excluded participants if they had a sex-specific cancer diagnosis discrepancy (e.g., endometrial cancer in male participants or prostate cancer in female participants; n = 157). Given physical activity data were collected in 2004, person-years and cancer cases diagnosed between baseline and 2004 (i.e., previous history of cancer in relation to physical activity data collection) were excluded due to potential changes in lifestyle behaviors post-diagnosis (n = 105,860). We further excluded participants if they reported extreme total energy intake (n = 3,361), were missing body mass index (BMI) or physical activity data (n = 153,503 total missing; n = 8,995 missing BMI; n = 149,033 missing physical activity; n = 4,525 missing both), were missing covariates (n = 14,908), or had extreme values for BMI or weekly minutes of moderate-to-vigorous physical activity (MVPA) (n = 2,133). Extreme values of total energy intake, BMI, and MVPA were defined as more than two interquartile ranges above the 75th percentile or below the 25th percentile on the logarithmic scale (23). Thus, 215,102 participants were included in the analysis.

2018 WCRF/AICR Score

We used the 2018 WCRF/AICR Score to estimate adherence to the 2018 WCRF/AICR Cancer Prevention Recommendations from the Third Expert Report (3, 5). The standardized scoring system operationalizes eight of the Recommendations related to body weight, physical activity, fruit/vegetables and fiber, fast foods [defined in the score as adapted ultra-processed foods (aUPFs) (9)], red and processed meat, sugar-sweetened drinks, alcohol, and optionally, breastfeeding (8, 9, 23). For this analysis, we did not include the breastfeeding component due to lack of breastfeeding data in the NIH-AARP Diet and Health Study (23). Therefore, total scores ranged from 0–7 points, where a higher score represents greater adherence to the Cancer Prevention Recommendations. **Table 1** details the breakdown of the 2018 WCRF/AICR Scoring system and how it was adapted in the current study.

Body weight

The score's body weight component was calculated from BMI (kg/m^2) based on self-reported height (feet and inches) and weight (pounds) at baseline. Though this score component is typically calculated from both BMI and waist circumference, data on waist circumference were not available for included participants. The point value for BMI was therefore doubled as recommended by Shams-White et al. to ensure that the body weight component retained its 0–1 point scoring range (**Table 1**) (8).

Physical activity

The physical activity score component was calculated based on MVPA data from the 2004 Follow-up Questionnaire. As reported above, the large amount of missing physical activity data was due to loss to follow-up in the cohort. Using guidance from the 2011 Compendium of Physical Activities, we used 15 activities included in the questionnaire to calculate total MVPA (24). As described previously (23), participants reported the average time spent weekly on each activity (none; 5 minutes; 10 minutes; 15 minutes; 30 minutes; 1 hour; 1 hour 30 minutes; 2–3 hours; 4–6 hours; 7–10 hours; >10 hours). For this analysis, we converted time value ranges to the mean value of the response option (i.e., 2–3, 4–6, and 7–10 hours were assumed to be 2.5, 5, and 8.5 hours, respectively); we re-estimated >10 hours as 10.5 hours.

Dietary intake

Dietary data were collected from participants at baseline via the NIH-AARP 124-item food frequency questionnaire (AARP-FFQ). The AARP-FFQ is an early version of the Diet History Questionnaire and assesses diet intake over the past 12 months (25); calibration and validation with two 24-hour dietary recalls are described elsewhere (22, 26, 27). As reported previously (23), we calculated nutrient and energy intake using the USDA Survey Nutrient Database associated with the Continuing Survey for Food Intake by Individuals 1994–1996 and the Nutrition Data System for Research database (University of Minnesota Nutrition Coordinating Center, 2004). As detailed in **Table 1**, we used these data to calculate the 2018 WCRF/AICR Score's five dietary components: plant-based foods (total fruits/vegetables excluding fruit juice and starchy vegetables, and total fiber); aUPFs; red and processed meat; sugar-sweetened drinks; and alcohol (9, 23). The data were also used to calculate total energy intake.

Outcomes

We obtained vital status and new cancer diagnoses of cohort participants from study enrollment in 1995–1996 through December 31, 2011 via annual linkages with the cancer registry, U.S. Social Security Administration Death Master File, follow-up searches of the

Table 1. 2018 WCRF/AICR scoring breakdown system.

Score component	Operationalization of recommendations		
	Recommended scoring	**Scoring adaptations[a]**	**Points**
1. Body weight	BMI (kg/m^2)	Points doubled	
	18.5–24.9		1
	25–29.9		0.5
	<18.5 or ≥30		0
	Waist circumference (inches)	Excluded	
	Male: <37 Female: <31.5		
	Male: 37–<40 Female: 31.5–<35		
	Male: ≥40 Female: ≥35		
2. Physical activity	Total MVPA (minutes/week)	None	
	≥150		1
	75–<150		0.5
	<75		0
3. Plant-based foods	Fruits and vegetables (grams/day)	Pyramid servings/day[b]	
	≥400	≥5	0.5
	200–<400	2.5–<5	0.25
	<200	<2.5	0
	Total fiber (g/day)	None	
	≥30		0.5
	15–<30		0.25
	<15		0
4. Fast-foods	% total kcal from ultra-processed foods	None[c]	
	Tertile 1	Tertile 1: 0.0–32.4	1
	Tertile 2	Tertile 2: >32.4–42.0	0.5
	Tertile 3	Tertile 3: >42.0–90.9	0
5. Red and processed meat	Total red & processed meat (g/week)	None	
	Red ≤500 and processed <21		1
	Red ≤500 and processed 21–<100		0.5
	Red >500 or processed ≥100		0
6. Sugar-sweetened drinks	Total sugar-sweetened drinks (g/day)	None	
	0		1
	>0–≤250		0.5
	>250		0
7. Alcohol	Total alcohol (g/day)[d]	None	
	0		1
	Male: >0–≤28; Female: >0–≤14		0.5
	Male: >28; Female: >14		0
Total score range			0–7

[a]Modifications to the scoring system were incorporated due to differences in units included in the dataset.
[b]Given that the 2018 WCRF/AICR Third Expert Report states five portions or servings is equivalent to 400 g and fruits and vegetables were available in the dataset as pyramid servings per day, the cut-points were converted from grams to servings per day. Starchy vegetables (including potatoes, beans, and peas) and fruit juice were excluded.
[c]Items already included in other 2018 WCRF/AICR Score components (e.g., red or processed meat; sugar sweetened drinks) were excluded to estimate adapted ultra-processed food (aUPF) intake. Kilocalorie intake was estimated for each aUPF item in the questionnaire and summed, then divide by total energy (kcal/day) and multiplied by 100 to calculate percent total kcal from aUPF. Tertiles were created based on all participants (i.e., males and females combined); ranges for each tertile are included in the table.
[d]One drink was defined as 14 g of alcohol.

National Death Index for those who correspond to the Social Security Administration Death Master File, and mailing responses (23). We defined cancer cases using the Surveillance Epidemiology and End Results (SEER) coding system (28). Participant follow-up ended with whichever came first: a new cancer diagnosis, mortality, or end of the follow-up period (December 31, 2011).

We took three approaches for categorizing cohort members according to their cancer diagnosis: (1) participants diagnosed with any of the 17 cancer types included in the 2018 WCRF/AICR Third Expert Report summary conclusions with evidence suggesting causal links to body weight, physical activity, dietary intake, and alcohol consumption (referred to herein as WCRF/AICR reviewed cancers), which included mouth, pharynx, and larynx; nasopharynx; esophagus (esophageal adenocarcinoma); lung; stomach; pancreas; gallbladder; liver; colorectum; breast; ovary; endometrium; cervix; prostate; kidney; bladder; and skin (melanoma only) (3); (2) participants diagnosed with any of the three most common U.S. cancer types in 2021 for males (lung, prostate, and colorectal cancers combined) and females (lung, breast, and colorectal cancers combined) (2); and (3) participants diagnosed with individual cancers contributing to the top three U.S. cancers. In these three approaches, we included only post-menopausal breast cancer diagnoses given our population age. Additionally, we excluded indolent prostate cancer diagnoses as prostate cancer cases. Prostate cancer cases were included if the cancer spread beyond the prostate (classified as T3-T4, N1, or M1) or the participant died of prostate cancer during study follow-up.

Statistical analysis

We used descriptive statistics to characterize the study population; means, standard deviations, and ranges were reported unless stated otherwise. We estimated Cox proportional hazard ratios (HRs) and 95% confidence intervals (CIs) for the association between 2018 WCRF/AICR Scores and risk for the WCRF/AICR reviewed cancers and top three U.S. cancers. The 2018 WCRF/AICR Score was included both as a continuous variable (i.e., assessing risk per 1-point increase) and with the following *a priori* categories: 0–2 points (ref); >2–<5 points; and 5–7 points (23). We stratified all models by sex and smoking status at baseline (never, former, current smoker) (23) and used person-years as the underlying time metric spanning the 2004–2011 study period. Similar to our prior analysis (23), multivariable models adjusted for covariates assessed at baseline: age (years) as of January 1, 2004; race/ethnicity (white, other); marital status (married, other); education (less than high school, high school graduate, some college, college graduate); self-reported history of diabetes (yes/no); status of menopausal hormone therapy (women only; never, former, current); and total energy (kilocalories/day). Lastly, we explored the independent associations of each component of the 2018 WCRF/AICR Score with cancer risk, with each model adjusting for the other six score components. Analyses were conducted using SAS statistical software (version 9.4; SAS Institute, Inc., Cary, NC). Statistical tests were two-sided with a significance level of 0.05.

Data availability statement

Data generated in this study are available upon request pending study proposal approval from the NIH-AARP Diet and Health Study Steering Committee.

Results

Participant characteristics

Among the 215,102 participants included in the study, there were 19,931 cases of WCRF/AICR reviewed cancers reported (males n = 11,066; females n = 8,865) between 2004 and 2011 during a mean 7.0 person-years of follow-up. Of these cases, 10,615 (53.3%) were due to the top three U.S. cancers in males (total n = 4,658; lung cancer n = 2,211; prostate cancer n = 920; colorectal cancer n = 1,527) and females (total n = 5,957; lung cancer n = 1,475; breast cancer n = 3,546; colorectal cancer n = 936).

Select baseline characteristics of study participants are included in **Table 2**. Fifty-eight percent of participants were male and the mean age for both males and females was 62 years at baseline enrollment. Most males were former smokers (58%) and married (87%), whereas most females were never smokers (49%) and less than half were married (47%). A small proportion of participants were current smokers (8% and 12% of males and females, respectively). The majority of participants were white and had some college education. In addition, most females reported that they either currently or never received hormone replacement therapy, and few participants reported a history of diabetes. Participants' mean BMI was 27 kg/m^2 and median weekly MVPA was 540 and 450 minutes among males and females, respectively.

Details on participant adherence to the 2018 WCRF/AICR Cancer Prevention Recommendations, as defined by the total 2018 WCRF/AICR Score and each component at baseline, are included in **Fig. 1** and Supplementary Table S1. Males and females had a mean score of 3.2 (SD = 0.9) and 3.5 (SD = 1.0) points, respectively, out of seven total points. The majority of participants met the recommendation for

Table 2. Distribution of select baseline characteristics of participants in the NIH-AARP Diet and Health Study (n = 215,102).

	Males[a]	Females[a]
Sample size [*n* (%)]	124,100 (57.7)	91,002 (42.3)
Age (years) [mean (SD), range]	61.7 (5.3), 50.3–71.5	61.6 (5.4), 50.3–71.5
Smoking [*n* (%)]		
Never	42,111 (33.9)	44,131 (48.5)
Former	71,815 (57.9)	36,158 (39.7)
Current	10,174 (8.2)	10,713 (11.8)
Race [*n* (%)]		
White	117,386 (94.6)	83,870 (92.2)
Other	6,714 (5.4)	7,132 (7.8)
Education [*n* (%)]		
Less than high school	21,294 (17.2)	25,749 (28.3)
High school graduate	11,137 (9.0)	9,907 (10.9)
Some college	26,923 (21.7)	23,264 (25.6)
College graduate	64,746 (52.2)	32,082 (35.3)
Marital status [*n* (%)]		
Married	108,331 (87.3)	42,811 (47.0)
Other[b]	15,769 (12.7)	48,191 (53.0)
Menopausal hormone therapy [*n* (%)]		
Never		39,579 (43.5)
Former		8,023 (8.8)
Current		43,400 (47.7)
Self-reported history of diabetes [*n* (%)]	9,906 (8.0)	5,005 (5.5)
BMI (kg/m^2) [mean (SD)]	27.0 (3.8)	26.5 (5.2)
Total moderate-vigorous physical activity (minutes/week) (median, IQR)	540.0, 275.0–955.0	450.0, 210.0–840.0
Total kcal/day (median, IQR)	1,865, 1,451–2,387	1,456, 1,128–1,862

[a]Males and females were compared using *t* tests, Wilcoxon–Mann–Whitney 2-sample rank sum tests, and chi-square test for differences; all comparisons were statistically significant (P < 0.0001).
[b]Other marital status included widowed, divorced, separated, and never married.

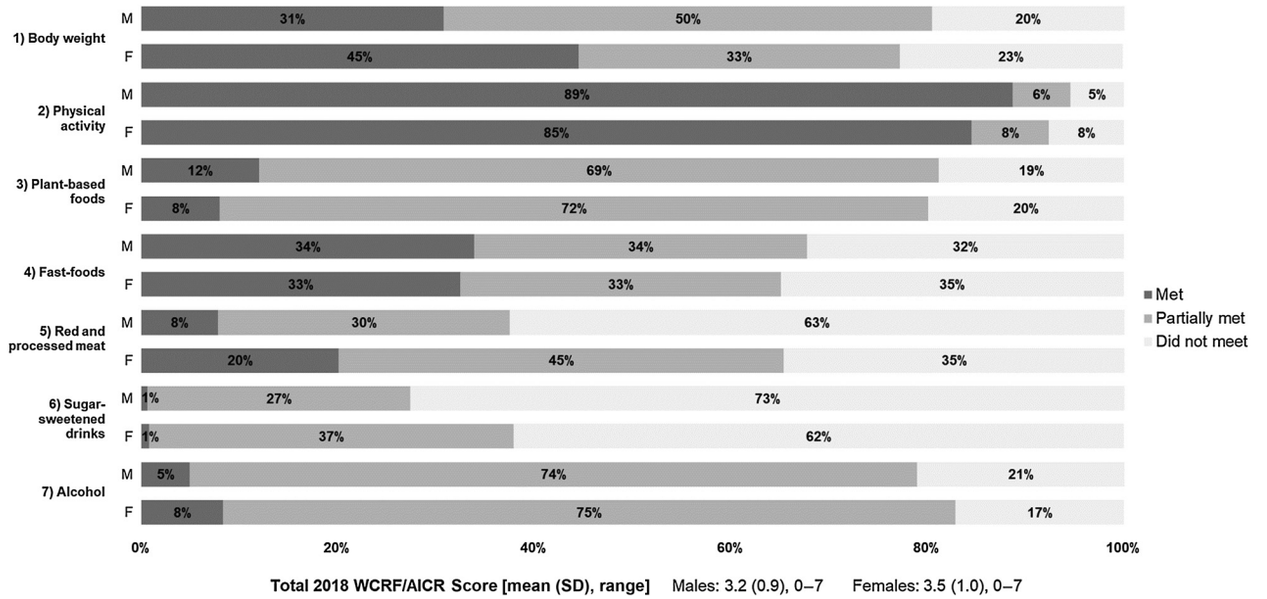

Figure 1.

Adherence to 2018 WCRF/AICR Score components ($n = 215,102$ total; $n = 124,100$ males; $n = 91,002$ females). Met = 1 point; partially met = 0.5 points; did not meet = 0 points.

physical activity and most participants met or partially met the recommendations for body weight. In addition, most participants partially met the recommendations for plant-based foods and alcohol but did not meet the recommendation for sugar-sweetened drinks. More females met or partially met the red and processed meat recommendation compared with males.

2018 WCRF/AICR Score and cancer risk

Results for the association between the 2018 WCRF/AICR Score and risk of WCRF/AICR reviewed cancers and the top three U.S. cancers are included in **Table 3**, stratified by sex and smoking status. For males, in adjusted models, each one-point increase in the 2018 WCRF/AICR Score was significantly associated with a reduced risk of WCRF/AICR reviewed cancers among never (HR, 0.94; 95% CI, 0.90–0.98) and former (HR, 0.92; 95% CI, 0.90–0.95) smokers, but not among current smokers. Each one-point score increase was also associated with a reduced risk of the top three U.S. cancers for males among former smokers only (HR, 0.89; 95% CI, 0.85–0.92). For females, each one-point score increase was associated with a 9% to 11% reduced risk of WCRF/AICR reviewed cancers and an 8% to 13% reduced risk of the top three U.S. cancers across smoking strata. When examining risk of each of the top three cancers, higher scores were associated with a decreased risk for lung cancer only among male former smokers (HR, 0.84; 95% CI, 0.79–0.89) and female current smokers (HR, 0.89; 95% CI, 0.82–0.96). Higher scores were also associated with a 7% to 19% decreased risk for post-menopausal breast cancer among females regardless of smoking status and a 10% to 14% decreased risk of colorectal cancer among male and female never and former smokers. Scores were not significantly associated with colorectal cancer risk among current smokers or prostate cancer in males regardless of smoking status.

When the score was categorized using *a priori* cut-points, never and former smokers with the highest scores (5–7 points) versus lowest scores (0–2 points) had a 21% to 30% reduced risk of WCRF/AICR reviewed cancers. Among current smokers, females with the highest scores had a 41% lower risk of WCRF/AICR reviewed cancers than those with the lowest scores, with nonsignificant findings for male current smokers. For the top three U.S. cancers for males, only former smokers with the highest scores had a reduced risk compared with those with the lowest scores (HR, 0.69; 95% CI, 0.55–0.87). Across smoking strata, females with the highest scores had a 24% to 42% lower risk of the top three cancers than those with the lowest scores.

When the top U.S. cancers were examined separately, only female never smokers with the highest scores had a lower risk of breast cancer compared with those with the lowest scores (HR, 0.72; 95% CI, 0.57–0.90). For lung cancer, when comparing those with highest scores to lowest scores, significant risk reductions were seen in male former smokers (HR, 0.57; 95% CI, 0.41–0.80) and female current smokers (HR, 0.54; 95% CI, 0.34–0.87); findings were nonsignificant in other smoker strata. For colorectal cancer, male and female former smokers with the highest scores compared with those with the lowest scores had a 40% to 44% reduced risk; findings in adjusted models were nonsignificant among male and female never and current smokers. WCRF/AICR Scores' associations with prostate cancer risk were nonsignificant.

2018 WCRF/AICR Score components and cancer risk

Associations of each 2018 WCRF/AICR Score component with cancer risk stratified by sex and smoking status are presented in **Table 4**. Greater adherence to the alcohol and plant-based foods recommendations were most consistently associated with the greatest reductions in cancer risk among most subgroups, ranging from 17% to 34% and 14% to 37% respectively, followed by adherence to the body weight and physical activity recommendations. Findings for other components were mixed depending on smoking status. For example, among former smokers only, the red and processed meat component was associated with reduced risk of the top three U.S. cancers among

Table 3. HRs and 95% CIs for cancer risk according to adherence to the 2018 WCRF/AICR Score (continuous and *a priori* categories) stratified by sex and smoking status ($n = 215,102$).

		Males ($n = 124,100$)				Females ($n = 91,002$)			
		2018 WCRF/AICR Score				2018 WCRF/AICR Score			
		Continuous	0–2 $n = 12,896$	>2–<5 $n = 106,004$	5–7 $n = 5,200$	Continuous	0–2 $n = 7,918$	>2 – <5 $n = 75,432$	5 – 7 $n = 7,652$
WCRF/AICR reviewed cancers									
Never smoker	No. of cases	2,844/42,111				3,606/44,131			
	Unadjusted	**0.95 (0.91–0.99)**	Ref	0.89 (0.78–1.00)	0.82 (0.67–1.00)	**0.92 (0.89–0.95)**	Ref	**0.86 (0.77–0.96)**	**0.72 (0.61–0.84)**
	Adjusted	**0.94 (0.90–0.98)**	Ref	**0.86 (0.76–0.98)**	**0.79 (0.64–0.96)**	**0.91 (0.88–0.94)**	Ref	**0.85 (0.76–0.96)**	**0.70 (0.59–0.82)**
Former smoker	No. of cases	6,638/71,815				3,709/36,158			
	Unadjusted	**0.94 (0.92–0.97)**	Ref	**0.89 (0.82–0.96)**	**0.82 (0.71–0.95)**	**0.92 (0.89–0.95)**	Ref	**0.85 (0.76–0.95)**	**0.75 (0.64–0.88)**
	Adjusted	**0.92 (0.90–0.95)**	Ref	**0.86 (0.80–0.93)**	**0.78 (0.67–0.90)**	**0.91 (0.88–0.94)**	Ref	**0.85 (0.76–0.94)**	**0.74 (0.63–0.87)**
Current smoker	No. of cases	1,584/10,174				1,550/10,713			
	Unadjusted	0.98 (0.92–1.04)	Ref	1.00 (0.87–1.15)	0.98 (0.64–1.51)	**0.91 (0.86–0.96)**	Ref	0.87 (0.75–1.00)	**0.63 (0.46–0.86)**
	Adjusted	0.96 (0.90–1.02)	Ref	0.97 (0.84–1.12)	0.96 (0.62–1.47)	**0.89 (0.84–0.94)**	Ref	**0.85 (0.73–0.98)**	**0.59 (0.43–0.81)**
Top 3 U.S. cancers									
Never smoker	No. of cases	938/42,111				2,232/44,131			
	Unadjusted	0.97 (0.90–1.04)	Ref	0.88 (0.70–1.09)	0.80 (0.57–1.13)	**0.93 (0.90–0.97)**	Ref	**0.85 (0.73–0.98)**	**0.76 (0.62–0.92)**
	Adjusted	0.95 (0.89–1.03)	Ref	0.85 (0.68–1.05)	0.77 (0.54–1.08)	**0.92 (0.88–0.96)**	Ref	**0.83 (0.72–0.96)**	**0.72 (0.59–0.88)**
Former smoker	No. of cases	2,809/71,815				2,527/36,158			
	Unadjusted	**0.90 (0.86–0.94)**	Ref	**0.78 (0.70–0.88)**	**0.72 (0.57–0.91)**	**0.92 (0.88–0.95)**	Ref	0.90 (0.79–1.03)	**0.76 (0.63–0.93)**
	Adjusted	**0.89 (0.85–0.92)**	Ref	**0.76 (0.68–0.85)**	**0.69 (0.55–0.87)**	**0.91 (0.88–0.95)**	Ref	0.90 (0.79–1.03)	**0.76 (0.62–0.92)**
Current smoker	No. of cases	911/10,174				1,198/10,713			
	Unadjusted	0.99 (0.91–1.07)	Ref	1.05 (0.87–1.27)	1.01 (0.57–1.79)	**0.89 (0.84–0.95)**	Ref	**0.81 (0.69–0.95)**	**0.62 (0.43–0.88)**
	Adjusted	0.97 (0.90–1.05)	Ref	1.02 (0.84–1.23)	0.98 (0.55–1.74)	**0.87 (0.82–0.93)**	Ref	**0.79 (0.67–0.93)**	**0.58 (0.41–0.83)**
Prostate cancer									
Never smoker	No. of cases	367/42,111							
	Unadjusted	1.03 (0.92–1.15)	Ref	1.24 (0.83–1.85)	0.82 (0.43–1.54)				
	Adjusted	1.02 (0.91–1.15)	Ref	1.20 (0.81–1.80)	0.80 (0.42–1.51)				
Former smoker	No. of cases	476/71,815							
	Unadjusted	1.04 (0.94–1.16)	Ref	0.92 (0.69–1.23)	1.44 (0.90–2.31)				
	Adjusted	1.05 (0.94–1.16)	Ref	0.93 (0.69–1.23)	1.44 (0.90–2.31)				
Current smoker	No. of cases	77/10,174							
	Unadjusted	1.10 (0.83–1.45)	Ref	1.67 (0.77–3.64)	1.39 (0.17–11.30)				
	Adjusted	1.13 (0.85–1.50)	Ref	1.71 (0.78–3.72)	1.54 (0.19–12.58)				
Breast cancer									
Never smoker	No. of cases					1,651/44,131			
	Unadjusted					**0.94 (0.90–0.99)**	Ref	**0.82 (0.69–0.97)**	**0.76 (0.60–0.95)**
	Adjusted					**0.93 (0.88–0.97)**	Ref	**0.79 (0.67–0.94)**	**0.72 (0.57–0.90)**
Former smoker	No. of cases					1,478/36,158			
	Unadjusted					**0.93 (0.88–0.98)**	Ref	0.97 (0.81–1.17)	0.83 (0.64–1.07)
	Adjusted					**0.91 (0.86–0.96)**	Ref	0.94 (0.78–1.13)	0.79 (0.61–1.02)
Current smoker	No. of cases					417/10,713			
	Unadjusted					**0.84 (0.76–0.93)**	Ref	0.91 (0.68–1.21)	0.67 (0.37–1.23)
	Adjusted					**0.81 (0.73–0.90)**	Ref	0.86 (0.64–1.15)	0.61 (0.33–1.13)

(Continued on the following page)

Table 3. HRs and 95% CIs for cancer risk according to adherence to the 2018 WCRF/AICR Score (continuous and *a priori* categories) stratified by sex and smoking status (n = 215,102). (Cont'd)

		Males (n = 124,100)				Females (n = 91,002)			
		2018 WCRF/AICR Score				2018 WCRF/AICR Score			
		Continuous	0–2 n = 12,896	>2–<5 n = 106,004	5–7 n = 5,200	Continuous	0–2 n = 7,918	>2 – <5 n = 75,432	5 – 7 n = 7,652
Lung cancer									
Never smoker	No. of cases	115/42,111				156/44,131			
	Unadjusted	1.16 (0.96–1.42)	Ref	0.84 (0.45–1.57)	1.28 (0.54–3.01)	0.94 (0.80–1.10)	Ref	0.84 (0.48–1.45)	0.91 (0.44–1.87)
	Adjusted	1.12 (0.92–1.37)	Ref	0.78 (0.42–1.47)	1.13 (0.48–2.68)	0.92 (0.79–1.08)	Ref	0.81 (0.47–1.42)	0.85 (0.41–1.75)
Former smoker	No. of cases	1,407/71,815				666/36,158			
	Unadjusted	**0.86 (0.81–0.91)**	Ref	**0.70 (0.60–0.81)**	**0.60 (0.43–0.84)**	0.94 (0.87–1.02)	Ref	1.06 (0.80–1.41)	0.81 (0.55–1.21)
	Adjusted	**0.84 (0.79–0.89)**	Ref	**0.67 (0.58–0.78)**	**0.57 (0.41–0.80)**	0.95 (0.88–1.03)	Ref	1.10 (0.83–1.46)	0.84 (0.56–1.26)
Current smoker	No. of cases	689/10,174				653/10,713			
	Unadjusted	1.00 (0.91–1.09)	Ref	1.07 (0.86–1.33)	0.93 (0.47–1.84)	**0.90 (0.83–0.98)**	Ref	**0.75 (0.60–0.93)**	**0.58 (0.36–0.94)**
	Adjusted	0.98 (0.89–1.07)	Ref	1.02 (0.82–1.27)	0.89 (0.45–1.77)	**0.89 (0.82–0.96)**	Ref	**0.74 (0.59–0.92)**	**0.54 (0.34–0.87)**
Colorectal cancer									
Never smoker	No. of cases	456/42,111				425/44,131			
	Unadjusted	**0.87 (0.79–0.97)**	Ref	**0.70 (0.53–0.94)**	0.69 (0.43–1.11)	**0.90 (0.82–0.99)**	Ref	0.99 (0.70–1.41)	0.71 (0.43–1.15)
	Adjusted	**0.87 (0.78–0.96)**	Ref	**0.69 (0.51–0.91)**	0.67 (0.42–1.08)	**0.90 (0.81–0.99)**	Ref	1.01 (0.71–1.44)	0.70 (0.42–1.14)
Former smoker	No. of cases	926/71,815				383/36,158			
	Unadjusted	**0.90 (0.83–0.97)**	Ref	0.87 (0.71–1.06)	**0.60 (0.39–0.95)**	**0.84 (0.76–0.93)**	Ref	**0.56 (0.42–0.75)**	**0.56 (0.36–0.87)**
	Adjusted	**0.88 (0.82–0.95)**	Ref	0.85 (0.69–1.03)	**0.58 (0.37–0.91)**	**0.86 (0.77–0.95)**	Ref	**0.60 (0.45–0.81)**	**0.60 (0.38–0.94)**
Current smoker	No. of cases	145/10,174				128/10,713			
	Unadjusted	0.89 (0.73–1.09)	Ref	0.83 (0.54–1.29)	1.21 (0.37–4.02)	1.00 (0.83–1.21)	Ref	0.85 (0.51–1.42)	0.64 (0.21–1.89)
	Adjusted	0.87 (0.71–1.07)	Ref	0.81 (0.52–1.26)	1.17 (0.35–3.89)	1.03 (0.85–1.25)	Ref	0.89 (0.53–1.48)	0.68 (0.23–2.03)

Note: HRs are calculated from attained person-years as the underlying time metric. WCRF/AICR reviewed cancers include mouth, pharynx, and larynx; nasopharynx; esophagus (esophageal adenocarcinoma); lung; stomach; pancreas; gallbladder; liver; colorectum; breast, post-menopause; ovary; endometrium; cervix; prostate; kidney; bladder; and melanoma. Top 3 U.S. cancers include prostate, lung and bronchus ("lung"), and colon and rectum ("colorectal") cancers in males and breast (post-menopause), lung, and colorectal cancers in females. Multivariable models are adjusted for age (years) as of January 1, 2004, race/ethnicity (white, other), marital status (married, other), education (less than high school, high school graduate, some college, college graduate), total energy intake (kilocalories/day), hormone replacement therapy (never, former, current), and self-reported history of diabetes (yes/no). Results with significant P values ($P < 0.05$) are bolded.

Table 4. HRs and 95% CIs for cancer risk according to adherence to the seven components of the 2018 WCRF/AICR Score stratified by sex and smoking status (n = 215,102).

	Males (n = 124,100)			Females (n = 91,002)		
	Smoking status			Smoking status		
	Never n = 42,111	Former n = 71,815	Current n = 10,174	Never n = 44,131	Former n = 36,158	Current n = 10,713
WCRF/AICR reviewed cancers						
Body weight	**0.83 (0.74–0.92)**	**0.85 (0.79–0.91)**	1.05 (0.91–1.21)	**0.82 (0.75–0.89)**	**0.86 (0.79–0.94)**	0.99 (0.87–1.13)
Physical activity	0.95 (0.81–1.11)	0.96 (0.87–1.06)	**0.81 (0.69–0.95)**	0.92 (0.81–1.03)	0.92 (0.82–1.03)	**0.75 (0.65–0.87)**
Plant-based foods	**0.84 (0.73–0.98)**	**0.78 (0.71–0.86)**	**0.74 (0.62–0.89)**	**0.86 (0.75–0.99)**	0.93 (0.81–1.06)	**0.68 (0.56–0.83)**
Fast-foods	1.05 (0.96–1.15)	0.99 (0.94–1.05)	1.11 (0.98–1.25)	0.94 (0.87–1.02)	0.93 (0.86–1.01)	1.03 (0.91–1.16)
Red and processed meat	1.02 (0.90–1.15)	0.97 (0.89–1.05)	0.96 (0.78–1.19)	0.96 (0.87–1.07)	**0.89 (0.81–0.99)**	0.96 (0.82–1.13)
Sugar-sweetened drinks	1.07 (0.91–1.26)	1.08 (0.98–1.20)	**1.29 (1.06–1.59)**	0.96 (0.84–1.10)	1.08 (0.95–1.23)	1.09 (0.89–1.33)
Alcohol	**0.73 (0.61–0.86)**	**0.83 (0.75–0.92)**	**0.72 (0.59–0.89)**	0.93 (0.80–1.07)	**0.83 (0.73–0.94)**	**0.66 (0.54–0.80)**
Top 3 U.S. cancers						
Body weight	**0.80 (0.66–0.96)**	0.90 (0.81–1.01)	1.13 (0.94–1.37)	**0.87 (0.78–0.97)**	**0.90 (0.81–1.00)**[a]	0.99 (0.85–1.16)
Physical activity	0.97 (0.73–1.28)	**0.84 (0.73–0.97)**	**0.71 (0.58–0.87)**	**0.85 (0.73–0.98)**	0.90 (0.79–1.03)	**0.71 (0.60–0.83)**
Plant-based foods	**0.75 (0.58–0.96)**	**0.68 (0.59–0.78)**	0.79 (0.62–1.00)	0.86 (0.73–1.02)	0.87 (0.74–1.02)	**0.63 (0.51–0.79)**
Fast-foods	1.12 (0.95–1.31)	0.92 (0.84–1.01)	1.16 (0.99–1.36)	0.91 (0.82–1.01)	0.97 (0.88–1.07)	1.02 (0.89–1.17)
Red and processed meat	1.06 (0.86–1.32)	**0.86 (0.76–0.99)**	0.86 (0.65–1.15)	1.08 (0.95–1.23)	**0.86 (0.76–0.97)**	0.94 (0.78–1.13)
Sugar-sweetened drinks	1.13 (0.85–1.51)	**1.22 (1.05–1.43)**	1.12 (0.85–1.46)	0.94 (0.79–1.11)	1.03 (0.88–1.21)	1.07 (0.85–1.34)
Alcohol	0.80 (0.59–1.08)	**0.82 (0.70–0.95)**	0.86 (0.66–1.13)	0.96 (0.80–1.16)	**0.83 (0.71–0.97)**	**0.68 (0.55–0.84)**

Note: HRs are calculated from attained person-years as the underlying time metric. WCRF/AICR reviewed cancers include mouth, pharynx, and larynx; nasopharynx; esophagus (esophageal adenocarcinoma); lung; stomach; pancreas; gallbladder; liver; colorectum; breast, post-menopause; ovary; endometrium; cervix; prostate; kidney; bladder; and melanoma. Top 3 U.S. cancers include prostate, lung, and bronchus ("lung"), and colon and rectum ("colorectal") cancers in males and breast (post-menopause), lung, and colorectal cancers in females. Multivariable models are adjusted for age (years) as of January 1, 2004, race/ethnicity (white, other), marital status (married, other), education (less than high school, high school graduate, some college, college graduate), total energy intake (kilocalories/day), hormone replacement therapy (never, former, current), and self-reported history of diabetes (yes/no), and the six remaining score components. Score components range from 0–1 point; components are examined on a continuous scale (i.e., per 0.25- or 0.5-point increase depending on the component; see **Table 1** for 2018 WCRF/AICR Scoring breakdown system). Results with significant P values ($P < 0.05$) are bolded.
[a]Upper CI rounded in the table from 0.998 to 1.00.

males and of both the top three cancers and WCRF/AICR cancers among females.

Discussion

This study examined the association between adherence to the 2018 WCRF/AICR Cancer Prevention Recommendations and cancer risk among older adults in the NIH-AARP Diet and Health Study. Each one-point increase in the 2018 WCRF/AICR Score was associated with a 6% to 13% reduced risk of the combined WCRF/AICR reviewed cancers and top three U.S. cancers across sex and smoking status groups, except male never smokers' risk for the top three U.S. cancers and male current smokers' risk for both combined cancer outcomes. Findings using the *a priori* score categories were more consistent among females than males. For males, when comparing those with the highest versus lowest scores, only never and former smokers had a reduced risk of WCRF/AICR reviewed cancers and former smokers had reduced risk of the top three U.S. cancers. Females with the highest scores had 24% to 42% lower risk of WCRF/AICR reviewed cancers and of the top three U.S. cancers compared with those with the lowest scores, with strongest associations among current smokers. We also observed associations between the 2018 WCRF/AICR Score and lower risk for individual top cancers in the United States, including breast cancer regardless of smoking status, lung cancer among male former smokers and female current smokers, and colorectal cancer among never and former smokers. The small proportion of current smokers and relatively low number of cancer cases in some subgroups when stratified by cancer type may have contributed to nonsignificant associations. However, the nonsignificant associations between the WCRF/AICR score and prostate cancer risk are consistent with that of a prior meta-analysis focused on 2007 WCRF/AICR scores (7). Overall, our findings support the importance of multiple lifestyle factors included in the 2018 WCRF/AICR Cancer Prevention Recommendations for reducing cancer risk among older adults.

Recent studies have examined associations of the standardized 2018 WCRF/AICR Score with total cancer risk (10) and risk of specific cancers (11, 13–15, 18, 19), of which the majority were conducted outside of the United States (10, 11, 13–15, 18). For example, among Swedish adults ages ∼60 years at baseline, each one-point score increase was associated with a 3% and 5% reduced risk of total cancer among males and females, respectively (10). These point estimates were lower in magnitude compared with the 6% to 13% risk reduction in this study, likely in part due to the focus on cancers with established links to lifestyle factors. In addition, among post-menopausal Spanish women, the score was inversely associated with breast cancer risk after adjustment for covariates, albeit not reaching statistical significance (HR, 0.74; 95% CI, 0.51–1.06) perhaps due to the small number of cases among the younger cohort (mean age 35.0 years at baseline; ref. 11). In the Prostate, Lung, Colorectal, and Ovarian (PLCO) Cancer Screening Trial prospective cohort among U.S. adults ages ≥65 years at baseline, each one-point score increase was associated with a 12% reduced risk of pancreatic cancer (19). Each of these studies derived the standardized 2018 WCRF/AICR Score from questionnaires administered at one timepoint (at baseline), similar to most variables in this study (except physical activity, assessed at one timepoint in 2004). A notable difference in this study's approach was stratification by smoking status, which revealed differences in cancer risk reduction (or no risk reduction) between never, former, and current smokers.

Other studies have applied alternate scoring systems to measure adherence to the 2018 WCRF/AICR Cancer Prevention guidelines (12, 16, 17), which limits the ability to compare findings. In the PREDIMED cohort of Spanish older adults (ages ≥67 years at baseline) with high risk of cardiovascular disease, each one-point increase in their score was associated with a 21% lower risk of colorectal cancer (12). The greater magnitude of the PREDIMED point estimate may be due to the high-risk adult population, compared with the relatively healthy adults in this study.

We also explored associations of each component of the 2018 WCRF/AICR Score with risk of WCRF/AICR reviewed cancers and the top three U.S. cancers. Greater adherence to the alcohol, plant-based foods, body weight, and physical activity recommendations was most consistently associated with reduced cancer risk, aligning with scientific consensus regarding these components as established protective lifestyle factors and risk factors for multiple cancers (3, 29–31). Among former smokers only, we also observed that greater adherence to the red and processed meat component was associated with reduced risk of the top three U.S. cancers among males and of both the top three cancers and WCRF/AICR cancers among females. However, these exploratory, by-component findings and the lack of other significant associations in by-component results should be interpreted with caution, given that the score is not meant to be disaggregated but rather interpreted as a whole. These exploratory findings can inform future methodological research on the independent and synergistic relationships between score components and how they may affect cancer risk.

Strengths and limitations

Study strengths include its large sample size and the prospective, longitudinal cohort design over a 7-year follow-up period. Using the 2018 WCRF/AICR Score also allows for a standardized approach to compare findings with other studies that examine associations between adherence to the 2018 WCRF/AICR Cancer Prevention Recommendations and cancer risk. Our inclusion of several cancer risk outcomes—the WCRF/AICR reviewed cancers and top three U.S. cancers—will further aid comparisons of findings to other studies and populations.

Several limitations should be considered. This analysis utilized self-reported height and weight data, in addition to self-reported weekly MVPA and diet collected via a 12-month FFQ—all of which were collected at one timepoint but assumed in our analyses to be constant over time. In addition, dataset limitations precluded the use waist circumference data in scoring the body weight component. Recall bias and measurement error of self-reported data introduce the potential for misclassification, which may have biased the risk estimates toward the null. Although we did stratify analyses by smoking status, we did not account for the intensity of smoking among former and current smokers or the time since quitting among former smokers, which introduces the possibility for residual confounding, particularly for the associations seen with lung cancer. In addition, the 2018 WCRF/AICR Score weights all components equally, despite the inclusion of several dietary factors. Our exploratory analysis suggests that alcohol, plant-based foods, body weight, and physical activity may be driving cancer risk in some subgroups. However, methodologic work beyond the scope of the current analyses is needed to further explore the impact of weighting between components and to develop modeling approaches that more closely examine the dynamic synergy among components. Furthermore, this is a relatively healthy, physically active, and predominantly white older adult population, therefore findings might not be generalizable to older adults in the United States. However, it is still valuable to examine whether benefits of adherence to the Cancer Prevention Recommendations are observable, and future research can examine whether associations differ in other studies with a wider range of health statuses. Finally, use of *a priori* score categories—which have the benefit of improving interpretability of findings when compared with the continuous score—may decrease statistical power and either reward or penalize participants with values near the category cut-points.

Conclusions

In this study of older adults in the NIH-AARP Diet and Health Study, we found that greater adherence to the 2018 WCRF/AICR Cancer Prevention Recommendations assessed using the standardized 2018 WCRF/AICR Score was associated with reduced cancer risk. These findings emphasize the importance of considering the combined contributions of multiple lifestyle factors for cancer prevention and the potential modifying role of smoking history. Similar research is warranted in other older adult populations, including those in the United States and globally.

Authors' Disclosures

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Authors' Contributions

A.R. Korn: Writing–original draft, writing–review and editing, interpretation of data. **J. Reedy:** Conceptualization, supervision, methodology, writing–review and editing, interpretation of data. **N.T. Brockton:** Writing–review and editing, interpretation of data. **L.L. Kahle:** Formal analysis, methodology, writing–review and editing, interpretation of data. **P. Mitrou:** Writing–review and editing, interpretation of data. **M.M. Shams-White:** Conceptualization, methodology, writing–original draft, writing–review and editing, interpretation of data.

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Note

Supplementary data for this article are available at Cancer Epidemiology, Biomarkers & Prevention Online (http://cebp.aacrjournals.org/).

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