Adherence to the WCRF/AICR 2018 recommendations for cancer prevention and risk of cancer: prospective cohort studies of men and women

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BACKGROUND: In 2018, the World Cancer Research Fund/American Institute for Cancer Research (WCRF/AICR) issued revised recommendations for cancer prevention. We examined the relation between adherence to these recommendations and risk of total cancer in two population-based Swedish prospective cohorts (29,451 men and 25,349 women).

METHODS: Standardized-WCRF/AICR 2018 and simplified-WCRF/AICR 2018 adherence scores were constructed based on the WCRF/AICR recommendations for body weight, physical activity, diet, alcohol consumption and dietary supplement use. Data were collected using a self-administered questionnaire.

RESULTS: During the 15.4 years of follow-up, 12,693 incident cancers were ascertained. The multivariable HR between extreme categories of the Standardized-WCRF/AICR 2018 score (4.1–7 vs. 0–2) was 0.88 (95% CI = 0.82–0.95) and for the Simplified score (5–8 vs. 0–2) was 0.85 (95% CI = 0.80–0.90); each 1-score increment in recommendation adherence was associated with 3% (95% CI = 1–5%) and 4% (95% CI = 2–5%) decreased risk, respectively. Based on the Simplified scoring, most participants (>90%) did not meet WCRF/AICR 2018 recommendations regarding consumption of plant foods, limited consumption of red/processed meat and ‘fast food’/processed food, and <50% of participants met the weight and physical activity recommendations.

CONCLUSIONS: Adherence to the 2018 WCRF/AICR recommendations substantially reduced the risk of total cancer. Given that many people do not meet the recommendations, there is a great potential for cancer prevention.

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established in 1987, when all women, born 1914–1948, from Västmanland and Uppsala counties, were invited to participate in a mammography screening programme. In 1997, women from the SMC completed the same questionnaire as the COSM participants, except for some sex-specific questions. In late autumn 1997, the questionnaire was returned by 48,850 men and 39,227 women. Participants of both cohorts well represented the general Swedish population in terms of age distribution, level of education as well as prevalence of obesity.4

A flow chart detailing the analytic study population is shown in Fig. 1. We excluded participants with an incorrect or missing personal identification number (297 men and 243 women), those who died prior to the start of follow-up, 1 January 1998 (55 men and 43 women), or those with a previous cancer other than non-melanoma skin cancer (2712 men and 1810 women). Moreover, the participants with extreme energy intake (440 men and 327 women; ±3 SDs from the mean value for log e-transformed energy intake) and those with implausible energy intake (133 men and 156 women), dietary supplement use (3525 men and 2751 women), body mass index (BMI) (1979 men and 517 women), waist-to-hip ratio (5745 men and 3988 women) or physical activity (4786 men and 4043 women) were excluded. Finally, 29,451 men and 25,349 women remained for the analysis.

Data collection
Information on education level, smoking status, weight, height, physical activity, diet, use of dietary supplements and medication use, including aspirin use, was collected on the questionnaire in 1997. BMI was calculated by dividing body weight (kilograms) by height squared (meters). Questions about physical activity were validated using 7-day activity reports and accelerometers among 116 participants, 56–75 years old, and correlations between total daily activity estimated by the questionnaire and measured by the accelerometers and by the 7-day activity reports were 0.38 (95% CI: 0.22–0.54) and 0.64 (95% CI: 0.45–0.83), respectively.5

Food and alcohol consumption was assessed with a validated 96-item food-frequency questionnaire (FFQ).6 Participants were asked to indicate how often over the previous year they had consumed each item by using eight predefined frequency categories, ranging from “never” to “≥3 times per day”. The frequencies of food consumption were converted to gram per day by multiplying the frequency of consumption of each food item by an appropriate age-specific portion size.

The questionnaire also included questions on family history of cancer and history of diabetes. Moreover, information on diagnosis of diabetes was collected via linkage with the Swedish National Diabetes Register and the Swedish National Patient Register (ICD-10 codes: E10–E14). Sex-specific information, such as hormone replacement therapy use, parity and age at first birth, was collected in the SMC.

Standardized- and Simplified-WCRF/AICR 2018 scoring criteria
The Standardized-WCRF/AICR 2018 and the Simplified-WCRF/AICR 2018 scores were calculated according to scoring criteria presented in Table 1. The components and scoring criteria to calculate the Standardized-WCRF/AICR 2018 score were based on the previously published guidelines by Shams-White et al.7 For the Standardized-WCRF/AICR 2018 score, 1 point is assigned for recommendation adherence, 0.5 points are assigned for partially following the recommendations and 0 points are assigned for those furthest from meeting the recommendations (scores 0, 0.5 and 1). For recommendations that included sub-recommendations (e.g., BMI and waist circumference as two parts of the ‘healthy weight’ recommendation), each sub-recommendation was scored separately with points of 0.5 given for fully meeting the sub-recommendation, 0.25 for partially meeting the sub-recommendation and 0 for those furthest from meeting the sub-recommendation, with the full recommendation still scoring a maximum of 1.0 when both sub-recommendations were met. In the Simplified-WCRF/AICR 2018 score, developed by our group, 1 point is assigned when fully meeting the criteria, and 0 when the criteria were not met (scores 0 or 1). After summing the points for each recommendation, the Standardized-WCRF/AICR 2018 score ranges from 0 to 7, and the Simplified-WCRF/AICR 2018 score ranges from 0 to 8, due to inclusion of the non-use of dietary supplements to the Simplified score but not to the Standardized score.

Identification of cancer cases and follow-up
Incident cases of total cancer were identified by linkage to the National Cancer Register, which is nearly 100% complete.7 Cancer cases were classified according to the International Classification of Diseases and Related Health Problems, 10th Revision (codes: C00-D48). Participants were followed from January 1, 1998, to the
Table 1. WCRF/AICR 2018 recommendations for cancer prevention—scoring components and criteria.

| Components                                | Scoring criteria | Components                                | Scoring criteria |
|-------------------------------------------|------------------|-------------------------------------------|------------------|
| Recommendation 1—be a healthy weight     |                  | Recommendation 4                           |                  |
| BMI (kg/m²) ≤18.5–24.9                    | 0.5              | BMI (kg/m²) 18.5–24.9                      | 1                |
| ≥25–29.9                                  | 0.25             | ≥<150                                      | 1                |
| <18.5 or ≥30                              | 0                | <75–149.9                                   | 1                |
| Waist circumference (cm)                  |                  | <75–149.9                                   | 1                |
| Men/Women <94/<80                         | 0.5              |    |                                              |
| 94–101.9                                  | 0.25             | ≥150                                      | 1                |
| 80–87.9                                   |                  | ≥102/≥88                                   | 0                |
| Recommendation 2—be physically active    |                  | Recommendation 5                           |                  |
| Moderate–vigorous physical activity (min/wk) |                  | Red meat <500 g/week and processed meat ≤21 g/week | 1 |
| ≥150                                      | 1                | Red meat <500 g/week and processed meat ≤21 g/week | 1 |
| 75–149.9                                  | 0.5              | Red meat <500 g/week and processed meat ≤21 g/week | 1 |
| <75                                       | 0                | Red meat <500 g/week and processed meat ≤21 g/week | 1 |
| Recommendation 3—eat a diet rich in whole grains, vegetables, fruits and beans | | Red meat <500 g/week and processed meat ≤21 g/week | 1 |
| Fruits and vegetables (g/day)             |                  | Fruits and vegetables (g/day)              |                  |
| ≥400                                      | 0.5              | Whole grains ≥175 g/day                    | 1                |
| 200–399.9                                 | 0.25             | and non-starchy vegetables/beans           |                  |
| <200                                      | 0                | ≥400 g/day and dietary fibre ≥30 g/day     |                  |
| Total fibre (g/day)                       |                  | <30                                        | 0.5              |
| ≥30                                       | 0.5              | 15–29.9                                    | 0.25             |
| <15                                       | 0                | <2 Servings/day                            |                  |
| Recommendation 4—Limit the consumption of ‘fast foods’ and others processed high in fat, starches or sugars | | Tertile 1                                  | 1                |
| Tertile 1                                 | 1                | Tertile 2                                  | 0.5              |
| Tertile 3                                 | 0                | Tertile 3                                  |                  |
| Recommendation 5—Limit the consumption of red and processed meat | | Red meat <500 g/week and processed meat ≤21 g/week | 1 |
| Red meat <500 g/week and processed meat ≤21 g/week | 1 | Red meat <500 g/week and processed meat ≤21 g/week | 1 |
| Red meat >500 g/week and processed meat >21 g/week | 1 | Red meat >500 g/week and processed meat >21 g/week | 1 |
| Recommendation 6—limit the consumption of sugar-sweetened drinks | | Red meat <500 g/week and processed meat ≤21 g/week | 1 |
| 0 g/day                                   | 1                | <1 Serving/day                             |                  |
| 0.1–250 g/day                             | 0.5              | 1 ≤2 drinks/day men; ≤1 drink/day women    |                  |
| ≥250 g/day                                | 0                | ≤2 drinks/day men; ≤1 drink/day women      |                  |
| Red meat <500 g/week and processed meat ≤21 g/week | 1 | Red meat <500 g/week and processed meat ≤21 g/week | 1 |
| Red meat >500 g/week and processed meat >21 g/week | 1 | Red meat >500 g/week and processed meat >21 g/week | 1 |
| Recommendation 7—Limit alcohol consumption |                  | 0 drinks/day                               |                  |
| 0 drinks/day                              | 1                | ≤2 drinks/day men; ≤1 drink/day women      |                  |
| ≤2 drinks/day men; ≤1 drink/day women     | 0.5              | ≤2 drinks/day men; ≤1 drink/day women      |                  |
| >2 drinks/day men; > 1 drink/day women    | 0                | >2 drinks/day men; >1 drink/day women      |                  |

Table 1 continued

| Components                                | Scoring criteria | Components                                | Scoring criteria |
|-------------------------------------------|------------------|-------------------------------------------|------------------|
| Recommendation 8—do not use supplements for cancer prevention |                  | Recommendation 9                           |                  |
| Not included in the score                 |                  | Not using supplements or 1 using non-normal |                  |

BMI, body mass index; WCRF/AICR, World Cancer Research Fund/American Institute for Cancer Research; n/s, no scoring.

1World Health Organization’s classification of normal weight.

2Scoring cut-offs were determined empirically, including the previously published result of the study conducted in the SMC and the COSM.

3Scoring cut-offs were determined empirically; whole grains included granary/whole-meal bread, crispbread, bran wheat/oats, cereals/muesli and dry oatmeal porridge and other porridge/gruel.

4Scoring cut-offs according to the WCRF/AICR 2018 recommendations: 1 non-starchy vegetables/fruits included lettuce, spinach, cabbage, cauliflower, broccoli/Brussels sprouts, carrots, beetroots, peppers, tomatoes, onion/leek, garlic, green peas and mixed frozen vegetables, apples/pears, bananas, orange/citrus fruits, fresh/frozen berries and other fruits; beans included one question about beans/lentils/pea soup consumption.

5Scoring cut-off was determined empirically; ‘Fast foods’ and others processed high in fat, starch or sugar products were classified based on the NOVA classification system, and included sugar/honey, white bread, pizza, fried potatoes, French fries, chips/popcorn/cheese puffs, buns/cakes, biscuits/wafers/rusks, gateau/pastries, sweets, chocolate, ice cream and margarines/spreads, full-fat salad dressing, full-fat mayonnaise, full-fat crème fraiche and full-fat cream.

6Scoring cut-offs according to the WCRF/AICR 2018 recommendations: 1 red meat (unprocessed) included pork, beef/veal and minced meat; processed meat included sausages, cold cuts/ham/salami, blood pudding/sausages and liver paté.

7Scoring cut-off was determined empirically; sugar-sweetened drinks included soft drinks/soda and juices.

8In all, 12 g of ethanol corresponds to one drink; alcohol included class I drinks (<2.25% ethanol by volume), class II beer (2.25–3.50%), class III beer (3.50%) and strong wine (>4%) alcohol and liquor.

9Scoring cut-off based on the WCRF/AICR 2018 recommendations.

Statistical analysis

Cox proportional hazard regression models were used to estimate the hazard ratios (HRs) and 95% confidence intervals (CIs) of the risk of total cancer in the combined cohorts, and separately for men and for women. Both scores, the Standardized and the Simplified-WCRF/AICR 2018 scores were divided into three categories of adherence: (1) low—0–2 points (reference group), (2) medium—2.1–4 (Standardized score), 3–4 points (Simplified score) and (3) high—4.1–7 points (Standardized score), 5–8 points (Simplified score).

The multivariable HRs were adjusted for age of participants in 1998 (years, continuous), sex, education (less than high school, high school and university), smoking status and pack-years of smoking (never; ex-smokers ≤20, 20–39 and ≥40 pack-years; current ≤20, 20–39 or ≥40 pack-years), height (centimetres and quartiles), aspirin use (yes, no), history of diabetes (yes, no) and family history of cancer (yes, no). In addition, the multivariable HRs for women were adjusted for hormone replacement therapy use (ever, never) and parity/age at first birth (nulliparous, age at first birth <26/1–2 children, age at first birth ≥26/2–3 children, age at first birth 26–30/1–2 children, age at first child birth 26–30/1–2 children, age at first child birth ≥31/1–2 children and age at first birth ≥31/≥3 children). Moreover, due to the lack of inclusion of dietary...
supplement use in the Standardized score by its creators,3 we adjusted the multivariable HRs for this score for supplement use (regular, no/non-regular). Missing data on educational level (0.4%), smoking status (1.2%), aspirin use (8.7%), hormone replacement therapy use (2.6%), parity (2.2%) and age at first birth (10.6%) were included in the models as separate categories.

Secondary analysis was conducted by examining associations between meeting (yes, no) each individual WCRF/AICR 2018 recommendation and the risk of total cancer using the Simplified scoring system, and these associations were adjusted as described above, and were mutually adjusted for the other recommendations.

The proportional hazard assumption was evaluated for both scores by regressing scaled Schoenfeld residuals against survival time, and there was no evidence of departure from the assumption. To calculate P values for trend, the WCRF/AICR 2018 scores were used as a continuous variable. A likelihood-ratio test was used to assess for effect modification by gender in relation to the risk of total cancer incidence. Furthermore, the shape of the associations between the Standardized- and Simplified-WCRF/AICR 2018 scores and total cancer incidence was examined by using a restricted cubic-spline regression analysis with three knots (at the 10th, 50th and 90th percentile).8 Moreover, sensitivity analyses were conducted by excluding the first 3 years of follow-up, and excluding participants who were diagnosed with diabetes before baseline.

Statistical analyses were performed using Stata 14.2 (StataCorp, College Station, TX); two-sided P values ≤ 0.05 were recognised statistically significant.

RESULTS

The median (range) of the Standardized-WCRF/AICR 2018 adherence score was 3.25 points (0–7), and the Simplified-WCRF/AICR 2018 score was 3.0 points (0–8). The Spearman correlation coefficient between both scores was 0.60 (P value <0.001). Age-standardised baseline characteristics of participants by categories of the Standardized- and Simplified-WCRF/AICR 2018 scores

### Table 2. Age-standardised baseline characteristics of 54,800 Swedish men and women by categories of the Standardized- and the Simplified-World Cancer Research Fund/American Institute for Cancer Research 2018 recommendation score (Standardized- and Simplified-WCRF/AICR 2018 score).

| Characteristics                              | Standardized-WCRF/AICR 2018 score, range (median) | Simplified-WCRF/AICR 2018 score, range (median) |
|----------------------------------------------|---------------------------------------------------|-------------------------------------------------|
| Number of people                             | 0–2 (1.75)                                       | 0–2 (2)                                         |
| Men, %                                       | 5,212                                            | 10,727                                          |
| Age at baseline, years                       | 40.1                                             | 40.1                                            |
| University education, %                      | 1.75                                             | 2.1                                             |
| Smoking status, %                            | 2.3                                              | 2.1                                             |
| Never                                        | 33.2                                             | 39.8                                            |
| Ex-smokers                                   | 44.5                                             | 45.2                                            |
| Current smokers                              | 51.2                                             | 48.0                                            |
| Aspirin use, %                               | 37.5                                             | 35.6                                            |
| Hypertension, %                              | 33.3                                             | 31.7                                            |
| Diabetes, %                                  | 29.3                                             | 30.2                                            |
| Family history of cancer, %                  | 33.6                                             | 33.6                                            |
| Height, cm                                   | 174 ± 9                                          | 172 ± 9                                         |
| Energy intake, kcal/day                      | 2573 ± 886                                       | 2377 ± 837                                      |
| Nulliparous, %                               | 6.2                                              | 8.3                                             |
| Age at first birth, years                    | 23.4 ± 4.9                                       | 23.9 ± 4.9                                      |
| Hormone replacement therapy use, %           | 41.5                                             | 49.2                                            |
| BMI, kg/m²                                   | 28.2 ± 4.0                                       | 27.1 ± 3.6                                      |
| Heavy manual labor, %                        | 2.0                                              | 1.2                                             |
| Walking/cycling ≥40 min/day, %               | 9.3                                              | 9.9                                             |
| Exercise ≥4 h/week, %                       | 5.7                                              | 7.4                                             |
| Whole grains, gram/day                       | 123 ± 99                                         | 128 ± 91                                        |
| Fruit/vegetables/beans, gram/day             | 257 ± 148                                        | 344 ± 199                                       |
| Dietary fibre intake, gram/day               | 25.3 ± 11.3                                      | 26.3 ± 10.4                                     |
| Fast food/other food high in fat/ starches/sugar, servings/day | 10.6 ± 4.7                                       | 7.8 ± 4.5                                       |
| Sugar-sweetened drinks, servings/day         | 1.5 ± 1.6                                        | 1.4 ± 1.5                                       |
| Unprocessed red meat, gram/day               | 58 ± 37                                          | 54 ± 39                                         |
| Processed red meat, gram/day                 | 43 ± 27                                          | 39 ± 29                                         |
| Alcohol, drinks/day                          | 1.8 ± 2.8                                        | 1.6 ± 2.0                                       |
| No use/non-regular supplement use, %         | 85.3                                             | 57.8                                            |

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*aResults presented for women.

*bIn all, 12 g of ethanol corresponds to one drink.
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Table 3. Hazard ratios (HRs) and 95% confidence intervals (CIs) of total cancer incidence by the categories of the Standardized-WCRF/AICR 2018 score and the Simpli-WCRF/AICR 2018 score in the Cohort of Swedish Men and the Swedish Mammography Cohort, follow-up 1998–2016.

| Standardized-WCRF/AICR 2018 score, range (median) | Per 1 point of WCRF/AICR | P-trend |
|---------------------------------------------------|--------------------------|---------|
| Men and women (n = 54,800)                        |                          |         |
| Cases                                             | 1289                     | 9353    | 2051 |
| Person-years                                      | 77,607                   | 617,476 | 146,527 |
| Age-adjusted HR (95% CI)                          | 1.00                     | 0.86 (0.81–0.91) | 0.74 (0.69–0.80) | 0.91 (0.89–0.93) | <0.001 |
| Multivariable-adjusted HR (95% CI)a               | 1.00                     | 0.94 (0.88–0.99) | 0.88 (0.82–0.95) | 0.97 (0.95–0.99) | 0.001 |
| Men (n = 29,451)                                  |                          |         |      |
| Cases                                             | 958                      | 5812    | 1013 |
| Person-years                                      | 52,851                   | 328,817 | 55,207 |
| Age-adjusted HR (95% CI)                          | 1.00                     | 0.88 (0.82–0.94) | 0.81 (0.74–0.89) | 0.95 (0.92–0.97) | <0.001 |
| Multivariable-adjusted HR (95% CI)a               | 1.00                     | 0.91 (0.85–0.97) | 0.86 (0.79–0.95) | 0.97 (0.94–0.99) | 0.013 |
| Women (n = 25,349)                                |                          |         |      |
| Cases                                             | 331                      | 3541    | 1038 |
| Person-years                                      | 24,755                   | 288,659 | 91,320 |
| Age-adjusted HR (95% CI)                          | 1.00                     | 0.92 (0.82–1.03) | 0.84 (0.74–0.95) | 0.94 (0.91–0.97) | <0.001 |
| Multivariable-adjusted HR (95% CI)a               | 1.00                     | 0.95 (0.85–1.06) | 0.87 (0.77–0.99) | 0.95 (0.92–0.98) | 0.001 |
| Men and women (n = 54,800)                        |                          |         |      |
| Cases                                             | 2,613                    | 8118    | 1962 |
| Person-years                                      | 161,674                  | 537,718 | 142,218 |
| Age-adjusted HR (95% CI)                          | 1.00                     | 0.91 (0.87–0.95) | 0.82 (0.77–0.87) | 0.95 (0.94–0.97) | <0.001 |
| Multivariable-adjusted HR (95% CI)a               | 1.00                     | 0.94 (0.90–0.98) | 0.85 (0.80–0.90) | 0.96 (0.95–0.98) | <0.001 |
| Men (n = 29,451)                                  |                          |         |      |
| Cases                                             | 1,631                    | 4931    | 1221 |
| Person-years                                      | 89,494                   | 274,706 | 72,676 |
| Age-adjusted HR (95% CI)                          | 1.00                     | 0.93 (0.88–0.98) | 0.82 (0.76–0.88) | 0.96 (0.94–0.98) | <0.001 |
| Multivariable-adjusted HR (95% CI)a               | 1.00                     | 0.94 (0.89–1.00) | 0.85 (0.79–0.91) | 0.97 (0.95–0.98) | 0.001 |
| Women (n = 25,349)                                |                          |         |      |
| Cases                                             | 982                      | 3,187   | 741  |
| Person-years                                      | 72,180                   | 263,013 | 69,542 |
| Age-adjusted HR (95% CI)                          | 1.00                     | 0.89 (0.83–0.96) | 0.79 (0.72–0.87) | 0.94 (0.91–0.96) | <0.001 |
| Multivariable-adjusted HR (95% CI)a               | 1.00                     | 0.90 (0.84–0.97) | 0.83 (0.73–0.88) | 0.94 (0.92–0.97) | <0.001 |

*aAdjusted for age (years, continuous), sex, education (less than high school, high school or university), smoking status and pack-years of smoking (never, past <20, 20–39 or ≥40 pack-years, or current <20, 20–39 or ≥40 pack-years), height (centimetres, quartiles), history of diabetes (yes, no), aspirin use (yes, no) and family history of cancer (yes, no).

*bAdjusted for covariates above plus dietary supplement use (regular or no/non-regular).

*cAdditionally adjusted for hormone replacement therapy use (ever, never) and parity/age at first birth (nulliparous, age at first birth <26/1–2 children, age at first birth ≥26/≥3 children, age at first birth 26–30/1–2 children, age at first birth 26–30/≥31 years, age at first birth ≥31/1–2 children and age at first birth ≥31/≥3 children).

were presented in Table 2. Men were less likely to fall into the highest score category for the Standardized, but this pattern was not observed to the same extent for the Simplified score. Compared with participants in the lowest categories of both scores, a lower percentage of those in the highest score categories had hypertension and were current or ex-smokers. With increasing Standardized and Simplified scores, mean BMI decreased, and physical activity increased. As expected, with higher values of both scores, consumption of whole grains, fruits, vegetables and beans increased, while consumption of ‘fast foods’ and other foods high in fat, starches and sugars, as well as sugar-sweetened drinks, unprocessed and processed red meat and alcohol decreased. The percentage of participants who did not use dietary supplements or who did not use supplements regularly decreased as the standardized score increased, while for the Simplified score, the opposite participant distribution was observed.

During an average 15.4 years of follow-up (841,610 person-years; 1998–2016), 12,693 participants (7783 men and 4910 women) were diagnosed with cancer. Statistically significant associations were observed between categories of the Standardized-WCRF/AICR 2018 score and total cancer incidence in the overall study population, as well as in men and in women when examined separately (Table 3). Participants in the highest category of the Standardized-WCRF/AICR 2018 score (4.1–7) compared with those in the lowest category (0–2) had a lower risk of cancer, HR = 0.88 (95% CI = 0.82–0.95) with HRs of 0.86 (95% CI = 0.79–0.95) in men and 0.87 (95% CI = 0.77–0.99) in women. No statistically significant interaction was observed between the Standardized-WCRF/AICR
Standardized score, we observed a linear dose adherence to the WCRF/AICR 2018 recommendations using the Examining the shape of the association between risk of cancer and Simplified distribution of participants according to the Standardized and 2018 score and sex for the risk of total cancer (Fig. 2); each 1-point increment was associated with a 3% (95% CI = 0.79–0.88). The solid curve shows the restricted cubic recommendations. Fund/American Institute for Cancer Research (WCRF/AICR) 2018 evidence as a function of adherence of the World Cancer Research Fig. 2 Multivariable-adjusted hazard ratio of total cancer incidence as a function of adherence of the World Cancer Research Fund/American Institute for Cancer Research (WCRF/AICR) 2018 recommendations. The solid curve shows the restricted cubic spline, and dashed–dotted lines show 95% confidence intervals. Distribution of participants according to the Standardized and Simplified-WCRF/AICR 2018 scores is presented as a histogram at the bottom of the figure.

2018 score and sex for the risk of total cancer (P interaction = 0.52). Examining the shape of the association between risk of cancer and adherence to the WCRF/AICR 2018 recommendations using the Standardized score, we observed a linear dose–response relationship (Fig. 2); each 1-point increment was associated with a 3% (95% CI = 1–5%; P-trend = 0.001) lower risk of cancer.

The results obtained using the Simplified-WCRF/AICR 2018 score were similar to those obtained using the Standardized-WCRF/AICR 2018 score (Table 3). Participants in the highest category of the Simplified-WCRF/AICR 2018 score (5–8) compared with those in the lowest category (0–2) had lower risk of cancer, with HRs of 0.85 (95% CI = 0.80–0.90) in total participants, 0.85 (95% CI = 0.79–0.91) in men and 0.80 (95% CI = 0.73–0.88) in women. Each 1-point increment in the Simplified score was associated with a 4% (95% CI = 2–5%; P-trend < 0.001) lower risk of cancer in participants.

In a sensitivity analyses, we excluded the first 3 years of follow-up (excluding 1475 men and 861 women, including 934 and 631 cancer diagnoses, respectively); the HR for cancer risk between the highest versus the lowest category of the Simplified-WCRF/AICR 2018 score was comparable to the results including all participants (HR = 0.85, 95% CI = 0.80–0.92). Further exclusion of participants who were diagnosed with diabetes at pre-baseline (additional excluding 2,304 men and 1,010 women, and 585 and 178 cancer diagnoses) slightly decreased the observed associations (HR = 0.82, 95% CI = 0.77–0.88).

We also examined the association between each individual WCRF/AICR 2018 recommendation and total cancer incidence using the Simplified score (Fig. 3). Meeting the recommendations for healthy weight and physical activity were associated with a 4% (95% CI = 0–7%) and 5% (95% CI = 2–9%), respectively, decreased risk of total cancer. Meeting the recommendations for limited red/processed meat and alcohol consumption were associated with a 10% (95% CI = −2–20%) and 6% (95% CI = 2–10%) decreased risk of cancer, respectively.

The majority of the study population did not meet the specific individual recommendations. This was consistent whether the recommendations were operationalised using the Simplified or Standardized scores (Fig. 4). The recommendations least likely to be met were limiting the consumption of red and processed meat (98% of participants based on the Simplified score), limiting ‘fast food’ and other processed foods high in fat, starches or sugar (92%) and consuming plant foods, i.e., diet rich in whole grains, vegetables, fruit and beans (90%). Moreover, half of the study population did not meet the healthy weight and the physical activity criteria, 51% and 54%, respectively.

**DISCUSSION**

In these two population-based prospective cohorts of men and women, adherence to the WCRF/AICR 2018 recommendations for cancer prevention was associated with reduced risk of total cancer. Depending on the score used, each 1-point increment in adherence to the WCRF/AICR 2018 recommendations was associated with a 3–4% lower risk of cancer.

To the best of our knowledge, this is the first study examining adherence to the revised WCRF/AICR 2018 recommendations for cancer prevention in relation to total cancer incidence. Our results are in line with previous findings from prospective studies that assessed the association with the 2007 recommendations.9–12 Adherence to the WCRF/AICR 2007 recommendations was associated with reduced risk of total cancer9–12 and of some specific cancers,9–13 as well as reduced risk of total cancer mortality.14–16

The results obtained using the Simplified-WCRF/AICR 2018 score were slightly stronger than those obtained using...
the recently developed Standardized-WCRF/AICR 2018 score, which was designed to provide consistency when comparing WCRF/AICR recommendation adherence across studies. The Simplified score developed by our group differs from the Standardized score in that it is more rigorous, including only options of “yes” or “no” for compliance, than the Standardized score, which provides partial credit for lower levels of compliance. It should also be noted that the Simplified score may be easier to use as it does not include sub-recommendations and partial adherence; thus, it could be easier to communicate to the general public. Thus, individuals can more easily estimate their adherence with the WCRF/AICR 2018 recommendations using the Simplified score than the Standardized score.

The results obtained using the Simplified score are informative, regarding adherence to specific recommendations. Analyses of individual WCRF/AICR 2018 recommendations indicate that healthy weight, high physical activity and limited consumption of alcohol were associated with statistically significant lower risk of total cancer. Similarly, results of the European Prospective Investigation into Cancer and Nutrition (EPIC) study for the WCRF/AICR 2007 recommendations demonstrated that body fatness, physical activity and moderation in alcohol consumption were associated with total cancer incidence in participants of nine...
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Author Contributions
Conception and design: J.K. and A.W. Data collection: A.W. and N.H. Data curation: N.J. and K.J. Data analysis and interpretation: J.K., H.R.H. and A.W. Paper writing: J.K and H.R.H. Review and editing: A.W. and N.H. All authors approve the final version of the paper. All authors are accountable for all aspects of the work.

Additional Information
Ethics approval and consent to participate: The study was performed according to the Declaration of Helsinki, and was approved by the Regional Ethical Review Board at Karolinska Institutet in Stockholm, Sweden. Completion of the questionnaire by the respondent was considered implied consent.

Consent to publish: Not applicable.

Data availability: The data and the analytical programme are stored on a highly secure institutional server under the supervision of A. Wolk (PI). Investigators may apply to access the study’s deidentiﬁed data through contact with the PI.

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