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A Prospective Analysis of Red and Processed Meat Consumption and Risk of Colorectal Cancer in Women

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ABSTRACT

Background: Red and processed meats have been implicated as risk factors in the development of colorectal cancer in U.S. women, but associations with cooking practices are less well established.

Methods: Data are from the Sister Study, a cohort of women ages 35 to 74 years from the United States and Puerto Rico who have a sister diagnosed with breast cancer. Red and processed meat consumption, meat cooking practices, and intake of common meat products were collected at baseline using self-administered questionnaires ($N = 48{,}704$). Multivariable HRs (HR_{adj}) and 95% confidence intervals (95% CI) were estimated.

Results: During a median 8.7 years' follow-up (range <1–12.7 years), 216 colorectal cancer cases were diagnosed. In categorical analyses, an increased risk of colorectal cancer was seen in the highest quartile of processed meat consumption compared with the lowest [$HR_{adj} = 1.52$ (95% CI, 1.01–2.30); $P_{trend} = 0.02$], and for specific meat products, including breakfast sausages [$HR_{adj} =$ 1.85 (95% CI, 1.30–2.64)] and bacon [$HR_{adj} = 1.46$ (95% CI, 1.01–2.11)]. The HR_{adj} for the highest quartile of red meat consumption was 1.04 (95% CI, 0.68–1.60), and little evidence of association was observed for cooking practices or doneness of red meat. We observed positive associations with specific red meat products when cooking methods were considered, for example, grilled/barbequed steaks [$HR_{adj} = 2.23$ (95% CI, 1.20–4.14)] and hamburgers [$HR_{adj} = 1.98$ (95% CI, 1.00–3.91)].

Conclusions: Higher reported daily intake of processed meats and consumption of barbecued/grilled red meat products were associated with increased risk of colorectal cancer in women.

Impact: Variability in colorectal risk risk by meat type and cooking method should be considered when evaluating meat consumption.

Introduction

Colorectal cancer is the third most diagnosed cancer and third leading cause of cancer-related mortality in U.S. women (U.S. NCI: https://seer.cancer.gov). Diet may play a critical role in the development of colorectal cancer, and excess consumption of some types of meat has been implicated as a risk factor. The U.S. population consumes more meat per capita than any other country (Organisation for Economic Cooperation and Development: https://doi.org/10.1787/fa290fd0-en), and total meat consumption in the United States has been steadily rising over the past century (1). There is substantial epidemiologic evidence on the relationship between red and processed meat consumption and risk of colorectal cancer. Hazard assessments by the International Agency for Research on Cancer (IARC; ref. 2) and the World Cancer Research Fund and the American Institute for Cancer Research (WCRF/AICR; ref. 3) concluded that processed meat consumption causes colorectal cancer. With somewhat lesser confidence, WCRF/AICR (3) found strong evidence of a probable increased risk in relation to colorectal cancer from red meat, and IARC (2) classified red meat as "probably carcinogenic to humans" (Group 2A) based on limited evidence in relation to colorectal cancer in humans.

In addition to the quantity and frequency of red and processed meat consumed, risk of colorectal cancer may vary by cooking preparation technique, doneness level, meat subtype, and/or specific meat product. Cooking meat at high temperatures and for longer durations can produce more mutagenic compounds (4). A systematic review of epidemiologic studies by Carr and colleagues (5) found risk of colorectal cancer was differentially associated with certain meat subtypes such as beef and lamb; evidence of risk from specific red and processed meat products (i.e., bacon, steak, and hamburgers) is less established. Moreover, contemporary meat exposures and cooking patterns have not been adequately captured as most cohort studies have primarily relied on food frequency questionnaires (FFQ) asked at enrollment more than 20 years ago and have not examined cooking preferences.

We aim to further examine the association between red and processed meat intake and risk of colorectal cancer in a recent cohort of U.S. women, and further characterize this relationship by exploring specific meat products and meat cooking practices.

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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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Methods

Study population and data collection

The Sister Study is a long-term prospective cohort study of women with no history of breast cancer, but who have had a sister diagnosed with breast cancer. The study's main purpose is to evaluate environmental and familial risk factors for breast cancer and other conditions. From 2003 to 2009, the study enrolled 50,884 women ages 35–74 years old from the United States and Puerto Rico (6), with an emphasis on enhancing recruitment of women from underrepresented

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populations. All participants completed a two-part computer-assisted telephone interview, a home visit consisting of biometric, biologic, and environmental sampling, and additional self-administered questionnaires that captured dietary and family history information. Participants are contacted annually for a brief update, and a more detailed follow-up questionnaire is administered every 2–3 years. The Sister Study was approved by the Institutional Review Board (IRB) of the National Institute of Environmental Health Sciences, NIH (Bethesda, MD) and the Copernicus Group IRB. Sister Study participants provided written informed consent, and follow-up data collection is on-going (6). This analysis included incident colorectal cancer diagnosed and reported through September 15, 2016 (Sister Study data release 6.0).

Exclusion criteria

Cohort participants were excluded if they withdrew from the study ($N = 2$), did not provide an FFQ and were, therefore, missing information on red and processed meat consumption ($N = 1,140$), or did not have adequate follow-up information on incident colorectal cancer ($N = 20$). Participants with a history of colorectal cancer at baseline ($N = 207$) were also excluded. Women with extreme values of estimated total caloric intake (<400 kcal/day and >4,000 kcal/day) were excluded ($N = 811$). After exclusion criteria, a total of 48,704 participants were included in the study, totaling 420,574.35 person-years of follow-up.

Outcome assessment

Information on incident primary colon [International Classification of Disease (ICD) 10: C18] and rectal (ICD10: C19–20) cancer diagnoses was collected on the annual follow-up questionnaire. If a participant was deceased, we consulted their next-of-kin. Participants who reported colorectal cancer diagnoses ($n = 216$) were asked to provide a copy of the diagnostic pathology report and/or consent for retrieval of pathology reports from relevant health care providers. Reported colorectal cancer was considered confirmed if the diagnosis was reported in their medical records ($N = 121$; 110 adenocarcinomas and 11 nonadenocarcinomas or unclear histology), which were abstracted by trained staff, or through linkage to the National Death Index (NDI; $N = 15$; data available through December 31, 2014). Remaining cases were determined from self-report only ($N = 69$) or through next-of-kin ($N = 11$); no pathology reports were available to confirm diagnoses. Among those with pathology reports, the positive predictive value of self-reported colorectal cancer was over 80%; therefore both self-reported and histologically confirmed cases were included in primary analyses. Participants with *in situ* disease or with a colon or rectal cancer of unknown origin ($N = 7$) were included with noncases.

Meat consumption and cooking practices

The main exposures of interest in this analysis were amount of red and processed meats consumed. Dietary information was collected via self-administered dietary history (e.g., cooking practices module) and the validated Block 98 FFQ (7) completed at enrollment (8, 9). Participants were asked if they ever ate various red, processed, and white meats; how often they ate those products in the past 12 months; and to indicate via pictures the amount of each product consumed during each meal. A separate cooking practices module asked participants about their usual preference of grilling, barbequing, pan-frying or oven-broiling steak, hamburgers, and pork chops, as well as the preferred doneness level of these meats and cooking preferences for bacon and sausage.

To determine estimated mean daily intake [in grams per day (g/day)] of red, processed, and white meat reported in the FFQ, aggregate food group variables were calculated using the 2011–2012 Food Patterns Equivalents Database (FPED) developed by the U.S. Department of Agriculture (USDA; ref. 10). The aggregate FPED variable for processed (cured) meat includes the following: frankfurters, sausages, bacon, corned beef, cured ham, and luncheon meat that are made from beef, pork, or poultry. For unprocessed red meat, we combined the FPED variable for unprocessed red meat that includes red meat subtypes for beef, veal, pork, lamb, game meat, and the variable for organ meat. The FPED aggregate variable for white meat includes the following meat subtypes: poultry (chicken, turkey, Cornish hens, duck, goose, quail, pheasant, game birds) and seafood (finfish, shellfish, and other seafood; ref. 10). We also examined total meat consumption as a sum of FPED variables for unprocessed red meat (including organ meat), processed meat, and white meat.

White meat subtypes examined include poultry and seafood. Other meat subtypes were examined using the FFQ, including pork and beef. In addition to aggregate food group variables and meat subtypes, intake of specific meat products was examined on the basis of the FFQ. Specific unprocessed red meat and processed meat products include the following: hamburgers/cheeseburgers, hot dogs/dinner sausages, ham/baloney/lunch meat, bacon, and breakfast sausages.

Statistical analysis

The association between meat consumption and incident colorectal cancer was examined using Cox proportional hazards regression to estimate the HRs and 95% confidence intervals (95% CI). Models used age (continuous) as the underlying time metric; no difference was seen when time since entry was used. Through diagnostic tests including plot analyses and time interaction models, we verified the Cox proportional hazards assumption was met. Red and processed meat were classified into statistical quartiles of exposure. To calculate linear trends across quartiles of exposure, the median value of each exposure quartile was assigned to each participant and included as a linear exposure term in the model. In addition to quartiles of meat exposure, we examined red and processed meat as continuous measures (per 50 g/day and 25 g/day increase, respectively).

Covariates chosen *a priori* based on literature included continuous variables for total estimated caloric intake (kcal/day), body mass index (BMI; kg/m^2), and total physical activity [total metabolic equivalents (MET)-hours per week, summed over sports/exercise and daily activities]; as well as categorical variables for highest educational attainment (high school or less, some college, Bachelor's degree or above), race/ethnicity (non-Hispanic white, non-Hispanic black, or other race/ethnicity), and first-degree family history of colorectal cancer (yes/no). All included covariates were assessed at baseline. Household income was ultimately not included due to the high frequency of missing data ($N = 1,910$). After excluding individuals with missing covariate information, data on 47,712 participants were included for our final adjusted models.

A number of additional sensitivity analyses were performed. We ran final models additionally adjusting for smoking status (never, former, current), alcohol consumption (nondrinker, light, moderate, heavy), menopausal status (yes/no), ever having had a colonoscopy (yes/no), fruit and vegetable intake (median cup equivalents), total dietary and supplemental calcium (mg/day), total fat intake (g/day), total fiber intake (g/day), total dairy intake (cup equivalents), dietary and supplemental folate intake (dietary folate equivalents), any regular NSAID use in the past 12 months (yes/no), and ever use of hormone replacement therapy (yes/no). We observed no difference in the

Table 1. Baseline characteristics of Sister Study participants by colorectal case status ($N = 48{,}704$).

Participant characteristics	Colorectal cancer (case)		Non–colorectal cancer (noncase)	
	216	100%	48,488	100%
Age at baseline, years (mean, range)	216	59.9 (36.6–75.9)	48,488	55.7 (35.0–76.5)
Follow-up time, years (mean, range)	216	5.0 (0.01–11.8)	48,488	8.7 (0.1–12.7)
Diagnosis source				
Medical report or NDI	136	63.0	—	—
Self-report/next-of-kin	80	37.0	—	—
Missing	0			
Race/ethnicity				
Non-Hispanic White	183	84.7	41,064	84.7
Non-Hispanic Black	18	8.3	3,901	8.1
Hispanic/other	15	6.9	3,513	7.3
Missing	0		10	
Educational attainment				
High school or less	22	10.2	7,391	15.3
Some college	83	38.4	16,274	33.6
Bachelor's degree or above	111	51.4	24,815	51.2
Missing	0		8	
Body mass index (kg/m^2; mean, range)	216	28.9 (18.0–56.8)	48,476	27.7 (11.5–72.1)
Smoking status				
Never	111	51.4	27,229	56.2
Former	85	39.4	17,351	35.8
Current	20	9.3	3,896	8.0
Missing	0		12	
Alcohol status				
Nondrinker (never/former)	46	21.3	9,109	18.8
Light (≤3 drinks per week)	107	49.5	26,348	54.4
Moderate (>3–7 drinks per week)	36	16.7	7,568	15.6
Heavy (>7 drinks per week)	27	12.5	5,385	11.1
Missing	0		78	
Menopausal status				
Premenopausal	34	15.7	16,650	34.4
Postmenopausal	182	84.3	31,808	65.6
Missing	0		30	
Family history of colorectal cancer	27	12.7	4,627	9.7
Missing	3		560	
Ever had colonoscopy	139	64.4	30,159	62.2
Missing	0		16	
NSAID use in the past 12 months	33	15.3	9,179	18.3
Missing	0		0	
Ever used HRT	109	50.7	21,980	45.5
Missing	1		151	
		Mean (range)		**Mean (range)**
Physical activity (total MET-hours per week)	213	46.0 (7.2–157.8)	48,078	50.8 (7.2–350.3)
Total caloric intake (kcal/day)	216	1,654.6 (429.8–3,768.6)	48,488	1,616.9 (400.2–3,997)
Unprocessed red meat intake (g/day)	216	31.2 (0–239.1)	48,488	28.4 (0–515.9)
Processed meat intake (g/day)	216	16.7 (0.4–60.6)	48,488	14.9 (0–165.6)
White meat intake (g/day)	216	44.5 (0–199.8)	48,488	42.6 (0–502.1)
Fruit and vegetable intake (cup eq)	216	3.5 (0.5–11.7)	48,488	3.4 (0–21.0)
Dairy intake (cup eq)	216	1.4 (0.1–5.5)	48,488	1.4 (0.02–9.4)
Fiber intake (g/day)	216	16.8 (4.6–44.3)	48,488	17.0 (0–82.4)
Fat intake (g/day)	216	69.8 (16.7–198.8)	48,488	67.8 (4.0–268.1)
Dietary and supplementary folate (DFE)	216	927.6 (140.5–2,579.6)	48,488	939.6 (22.1–3,865.1)
Dietary and supplementary calcium (mg/d)	216	1,261.4 (205.2–3,132.7)	48,488	1,292.2 (63.0–5,738.8)

Abbreviations: DFE, dietary folate equivalents; HRT, hormone replacement therapy.

estimated HRs. To evaluate the robustness of findings, we evaluated two additional methods for limiting participants based on implausible caloric intake, including restricting extreme values to the interquartile range from the 25th and 75th percentiles, and limiting to those between 500 and 5,000 kcal/day. To examine the influence of energy intake, we also used the nutrient density method (11) to control for confounding by total energy intake (12). We also tested mutually controlling for other meat types as continuous variables in our final models. We excluded organ meat from the unprocessed red meat aggregate variable, and instead treated organ meat as a confounder in

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Table 2. Crude and adjusted[a] association between unprocessed red and processed meat consumption, meat subtypes, and specific meat products and risk of colorectal cancer.

Meat type		Continuous	Quartile 1 (Ref)	Quartile 2	Quartile 3	Quartile 4	P_{trend} [b]
Aggregate meat variables							
Total meat[c]	*N* cases (*N* adjusted)	216 (210)	50 (49)	52 (51)	50 (48)	64 (62)	
	Median g/day	74.59 (1.0–651.0)	33.51	60.95	90.49	144.95	
	Crude, HR (95% CI)	**1.13**[e] **(1.02–1.27)**	1.0	1.07 (0.72–1.57)	1.06 (0.72–1.57)	1.40 (0.96–2.03)	0.09
	Adjusted, HR_{adj} (95% CI)	1.10[e] (0.95–1.27)	1.0	1.03 (0.69–1.54)	0.98 (0.65–1.50)	1.26 (0.80–1.98)	0.30
Unprocessed red meat	*N* cases (*N* adjusted)	216 (210)	51 (51)	53 (52)	53 (50)	59 (57)	
	Median g/day (range)	21.21 (0.0–515.9)	7.31	16.16	27.75	53.50	
	Crude, HR (95% CI)	1.23[e] (1.00–1.52)	1.0	1.07 (0.73–1.58)	1.10 (0.75–1.61)	1.24 (0.85–1.81)	0.24
	Adjusted, HR_{adj} (95% CI)	1.14[e] (0.88–1.48)	1.0	1.00 (0.68–1.49)	0.96 (0.64–1.44)	1.04 (0.68–1.60)	0.76
Processed meat	*N* cases (*N* adjusted)	216 (210)	49 (49)	48 (47)	48 (47)	71 (67)	
	Median g/day (range)	11.17 (0.0–165.6)	4.25	8.62	14.49	28.31	
	Crude, HR (95% CI)	**1.40**[f] **(1.12–1.75)**	1.0	1.03 (0.69–1.53)	1.09 (0.73–1.63)	**1.70 (1.18–2.45)**	**0.002**
	Adjusted, HR_{adj} (95% CI)	1.28[f] (0.98–1.67)	1.0	0.98 (0.66–1.48)	1.02 (0.68–1.55)	**1.52 (1.01–2.30)**	**0.02**
White meat[d]	*N* cases (*N* adjusted)	216 (210)	50 (49)	58 (55)	47 (46)	61 (60)	
	Median g/day	33.99 (0.0–502.1)	13.07	26.39	43.18	77.17	
	Crude, HR (95% CI)	1.11[e] (0.92–1.34)	1.0	1.20 (0.82–1.75)	0.97 (0.65–1.45)	1.30 (0.89–1.88)	0.36
	Adjusted, HR_{adj} (95% CI)	1.04[e] (0.84–1.30)	1.0	1.12 (0.77–1.79)	0.92 (0.60–1.39)	1.17 (0.77–1.79)	0.61
Meat subtypes							
Beef	*N* cases (*N* adjusted)	216 (210)	66 (64)	33 (32)	63 (61)	54 (53)	
	Median g/day	2.80 (0.0–249.3)	0.00	1.40	5.67	13.08	
	Crude, HR (95% CI)	1.08[f] (0.86–1.34)	1.0	1.35 (0.89–2.06)	1.34 (0.95–1.90)	1.18 (0.82–1.69)	0.40
	Adjusted, HR_{adj} (95% CI)	1.05[f] (0.83–1.32)	1.0	1.49 (0.97–2.29)	1.41 (0.99–2.01)	1.18 (0.81–1.70)	0.48
Pork	*N* cases (*N* adjusted)	216 (210)	68 (66)	28 (28)	73 (72)	47 (44)	
	Median g/day	1.45 (0.0–258.1)	0.00	1.45	3.39	13.54	
	Crude, HR (95% CI)	1.09[f] (0.80–1.50)	1.0	1.21 (0.78–1.89)	1.32 (0.95–1.84)	1.30 (0.90–1.89)	0.18
	Adjusted, HR_{adj} (95% CI)	1.00[f] (0.71–1.42)	1.0	1.34 (0.86–2.09)	**1.42 (1.01–1.99)**	1.25 (0.85–1.84)	0.35
Poultry	*N* cases (*N* adjusted)	216 (210)	56 (55)	51 (49)	45 (43)	64 (63)	
	Median g/day	19.48 (0.0–486.2)	6.15	14.20	25.60	50.97	
	Crude, HR (95% CI)	1.09[f] (0.96–1.24)	1.0	0.95 (0.65–1.39)	0.87 (0.59–1.30)	1.30 (0.90–1.86)	0.12
	Adjusted, HR_{adj} (95% CI)	1.05[f] (0.91–1.22)	1.0	0.90 (0.61–1.33)	0.80 (0.53–1.21)	1.18 (0.79–1.76)	0.27
Seafood	*N* cases (*N* adjusted)	216 (210)	57 (55)	50 (49)	47 (46)	62 (60)	
	Median g/day	11.23 (0.0–359.6)	3.32	8.25	15.08	31.84	
	Crude, HR (95% CI)	1.03[f] (0.86–1.24)	1.0	0.85 (0.58–1.24)	0.77 (0.52–1.13)	0.99 (0.69–1.42)	0.88
	Adjusted, HR_{adj} (95% CI)	0.98[f] (0.80–1.20)	1.0	0.83 (0.56–1.22)	0.74 (0.49–1.10)	0.90 (0.61–1.34)	0.84
Specific unprocessed red and processed meat products							
Hamburgers, cheeseburgers	*N* cases (*N* adjusted)	216 (210)	49 (48)	55 (54)	79 (76)	33 (32)	
	Median g/day	4.87 (0.0–219.0)	0.61	2.43	5.62	20.86	
	Crude, HR (95% CI)	1.28[f] (0.95–1.73)	1.0	1.13 (0.77–1.66)	1.27 (0.89–1.81)	1.46 (0.94–2.27)	0.09
	Adjusted, HR_{adj} (95% CI)	1.17[f] (0.84–1.62)	1.0	1.11 (0.75–1.65)	1.18 (0.81–1.71)	1.29 (0.80–2.07)	0.28
Ham, baloney, lunch meat	*N* cases (*N* adjusted)	216 (210)	61 (61)	41 (40)	68 (66)	46 (43)	
	Median g/day	1.87 (0.0–112.0)	0.46	1.39	4.31	24.26	
	Crude, HR (95% CI)	1.28[f] (0.95–1.73)	1.0	0.91 (0.61–1.36)	1.14 (0.80–1.61)	1.42 (0.97–2.09)	**0.04**
	Adjusted, HR_{adj} (95% CI)	1.18[f] (0.85–1.64)	1.0	0.87 (0.58–1.30)	1.07 (0.75–1.52)	1.25 (0.83–1.88)	0.15

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Table 2. Crude and adjusted[a] association between unprocessed red and processed meat consumption, meat subtypes, and specific meat products and risk of colorectal cancer. (Cont'd)

Meat type		Continuous	Quartile 1 (Ref)	Quartile 2	Quartile 3	Quartile 4	P_{trend}[b]
Bacon	*N* cases (*N* adjusted)	216 (210)	64 (62)	31 (31)	58 (57)	63 (60)	
	Median g/day	0.43 (0.0–25.6)	0.11	0.31	0.63	1.97	
	Crude, HR (95% CI)	**2.29[g] (1.27–4.13)**	1.0	1.02 (0.67–1.57)	**1.44 (1.01–2.06)**	**1.58 (1.11–2.24)**	**0.01**
	Adjusted, HR_{adj} (95% CI)	**2.07[g] (1.10–3.94)**	1.0	1.02 (0.66–1.58)	1.41 (0.98–2.02)	**1.46 (1.01–2.11)**	**0.03**
Hot dogs, dinner sausages	*N* cases (*N* adjusted)	216 (210)	90 (87)	32 (32)	46 (45)	48 (46)	
	Median g/day	1.48 (0.0–180.0)	0.74	1.48	1.50	6.92	
	Crude, HR (95% CI)	1.07[g] (0.77–1.49)	1.0	1.11 (0.74–1.67)	1.03 (0.72–1.47)	1.36 (0.95–1.93)	0.09
	Adjusted, HR_{adj} (95% CI)	0.93[g] (0.62–1.40)	1.0	1.08 (0.72–1.63)	0.99 (0.69–1.42)	1.23 (0.84–1.79)	0.21
Breakfast sausages	*N* cases (*N* adjusted)	216 (210)	60 (59)	52 (52)	24 (22)	80 (77)	
	Median g/day	0.89 (0.0–81.0)	0.00	0.45	0.90	3.86	
	Crude, HR (95% CI)	**1.57[g] (1.26–1.97)**	1.0	0.98 (0.68–1.42)	0.91 (0.57–1.47)	**1.98 (1.42–2.78)**	**<0.001**
	Adjusted, HR_{adj} (95% CI)	**1.47[g] (1.14–1.90)**	1.0	0.97 (0.67–1.41)	0.83 (0.51–1.35)	**1.85 (1.30–2.64)**	**<0.001**

Note: Significant ($P < 0.05$) values are bolded.
[a]Model adjusted for total calories (kcal/day, continuous), BMI (kg/m^2, continuous), highest educational attainment (high school or less, some college, Bachelor's degree, and above), physical activity (MET-h/wk), race/ethnicity (non-Hispanic White, non-Hispanic Black, Hispanic/other), and family history of colorectal cancer (yes/no).
[b]P_{trend} calculated using assigning the median value of each quartile.
[c]Total meat is a sum variable of red meat (including organ meat), processed meat, and white meat.
[d]White meat includes seafood and poultry.
[e]Per 50 grams/day.
[f]Per 25 grams/day.
[g]Per 10 grams/day.

unprocessed red meat and colorectal cancer models. Other meat consumption variables, including white meat intake and specific meat types, were examined to further characterize risk of colorectal cancer. In continuous models, we report increments of 50 g/day for aggregate meats (total meat and white meats), 25 g/day for meat subtypes (beef, pork, poultry, and seafood), as well as for hamburgers and lunch meats, and 10 g/day for other specific red meat and processed meat products (hot dogs, bacon, and breakfast sausages). Shellfish was also separately examined as a meat subtype. Cooking methods and doneness levels of certain red meat products were examined by quantity of consumption reported in the FFQ. Those who reported a preferred cooking method and doneness level for specific meat products were also evaluated.

Effect modification was tested by including separate interaction terms for meat exposures and age, and meat exposures and BMI. We conducted subgroup analyses stratifying by baseline age (<55 years, 55+ years old), overweight status (normal, overweight, obese; excluding underweight), and outcome reporting type (self or next-of-kin reported only vs. medically- or NDI-confirmed). We also explored excluding those reporting other cancer diagnoses at baseline (not including nonmelanoma skin cancers), and, separately, those who reported a family history of colorectal cancer at baseline ($N = 27$). We also excluded colorectal cancer diagnoses that occurred within one ($N = 17$) and two ($N = 38$) years after baseline. Tumor anatomic site-specific analyses by colon and rectal cancers were also examined separately.

All analyses were completed using STATA software 14.2 (StataCorp).

Results

Of the 48,704 participants, 216 women had incident colorectal cancer over a median 4.8 years of follow-up (range, <1–12.7 years). Compared with noncases, women with colorectal cancer were more likely to be older, postmenopausal, have a greater than high school education, have a family history of colorectal cancer, have a higher BMI, and be less physically active (**Table 1**). Mean intake of unprocessed red meat (31.2 vs. 28.4 g/day) and processed meat (16.7 vs. 14.9 g/day) were higher in cases.

The crude and adjusted associations between intake of aggregate meats, including red and processed meats, and meat subtypes and colorectal cancer are shown in **Table 2**. When examined in continuous models, a positive association between processed meat consumption and colorectal cancer was seen, with a HR_{adj} of 1.28 (95% CI: 0.98–1.67) for every 25 g/day increase. An increased risk of colorectal cancer was also seen in the highest quartile of processed meat consumption [$HR_{adj} = 1.52$ (95% CI: 1.01–2.30)], compared with the lowest quartile, with a positive exposure–response relationship ($P_{trend} = 0.02$). Unprocessed red meat consumption was elevated but nonsignificantly associated with risk of colorectal cancer when modeled continuously [$HR_{adj} = 1.14$ (95% CI: 0.88–1.48) for every 50 g/day increase]; the HR_{adj} for Q4 vs. Q1 was 1.04 (95% CI: 0.68–1.60). Elevated adjusted HRs were seen in the highest quartiles of total meat, white meat, and poultry subtype. Adjusted HRs below 1 were seen for seafood consumption in lower quartiles of consumption. Adjusted HRs were 1.18 (95% CI: 0.81–1.70) and 1.25 (95% CI: 0.85–1.84) in the highest quartile for beef and pork subtypes, respectively.

Of the specific red and processed meat products, hamburgers and cheeseburgers had the highest median intake (4.87 g/day), while bacon had the lowest (0.43 g/day). A 10 g/day increase in bacon consumption was associated with a 2-fold increased risk of colorectal cancer [$HR_{adj} = 2.07$ (95% CI: 1.10–3.94)] and for the highest versus lowest quartile

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Table 3. Multivariable HR_{adj}[a] for the association between red meat intake by cooking practice and/or doneness level and risk of colorectal cancer.

Red meat cooking method and/or doneness		Continuous (50 g/day)	Quartile 1 (Ref)	Quartile 2	Quartile 3	Quartile 4	P_{trend}[b]
Grilled red meat	*N* cases	210	60	46	62	42	
	Median g/day	2.43	0.0	1.20	5.62	20.86	
	HR_{adj} (95% CI)	1.20 (0.83–1.73)	1.0	1.23 (0.84–1.82)	1.31 (0.91–1.88)	1.20 (0.80–1.80)	0.62
Grilled red meat (excl. pork)	*N* cases	203	56	46	61	40	
	Median g/day	2.43	0.0	1.23	5.62	20.86	
	HR_{adj} (95% CI)	1.35 (0.90–2.01)	1.0	1.29 (0.87–1.92)	1.32 (0.91–1.91)	1.28 (0.84–1.94)	0.49
Pan-fried red meat[c]	*N* cases	210	155	—	—	55	
	Median g/day	0.0	0.0	—	—	5.62	
	HR_{adj} (95% CI)	0.99 (0.47–2.06)	1.0	—	—	1.01 (0.74–1.38)	0.90
Medium-well to charred red meat	*N* cases	208	62	39	57	50	
	Median g/day	2.43	0.0	1.23	5.62	10.43	
	HR_{adj} (95% CI)	0.99 (0.61–1.61)	1.0	0.99 (0.66–1.48)	1.14 (0.79–1.64)	1.03 (0.70–1.51)	0.73
Grilled and medium-well to charred red meat[c]	*N* cases	210	117	—	42	51	
	Median g/day	0.0	0.0	—	2.43	10.43	
	HR_{adj} (95% CI)	0.72 (0.33–1.60)	1.0	—	0.89 (0.62–1.26)	1.01 (0.72–1.41)	0.90

Note: Significant ($P < 0.05$) values are bolded.
[a]Model adjusted for total calories (kcal/day, continuous), BMI (kg/m^2, continuous), highest educational attainment (high school or less, some college, Bachelor's degree and above), physical activity (MET-h/wk, continuous), race/ethnicity (non-Hispanic White, non-Hispanic Black, Hispanic/other), and family history of colorectal cancer (yes/no).
[b]P_{trend} calculated using assigning the median value of each quartile.
[c]For pan-fried meat, quartiles 1–3 are combined. For grilled and medium-well to charred red meat, quartiles 1–2 are combined.

of intake [HR_{adj} = 1.46 (95% CI: 1.01–2.11)], with an increasing exposure-response trend (P_{trend} = 0.03). Similarly, breakfast sausage modeled continuously [HR_{adj} = 1.47 (95% CI: 1.14–1.90) for every 10 g/day increase] and the highest quartile of intake [HR_{adj} = 1.85 (95% CI: 1.30–2.64)] were associated with higher risk of colorectal cancer, with a positive exposure–response relationship (P_{trend} < 0.001). Most upper quartiles of hamburger, lunch meat, and dinner sausage intake showed positive associations, relative to the first quartile of intake.

Tables 3 and **4** report analyses for cooking methods and doneness of red meat. Adjusted HRs were elevated for all levels of intake for grilled red meat with and without inclusion of pork, but no other patterns emerged (**Table 3**). In analyses of specific red meat products evaluated by cooking method preference or doneness preference, risks were elevated (HR_{adj} > 1.50) in all cooking methods or doneness levels for steak and hamburgers (compared with participants who did not eat that meat type), and were statistically significant among participants who preferred eating steak and hamburgers that were grilled/barbequed or cooked to rare/medium-rare doneness (**Table 4**). When grilled/barbequed steak and hamburgers were combined with doneness preference, similar elevated HRs were seen for all categories of doneness preference.

We did not see a significant interaction between aggregate red and processed meat consumption and either age or BMI when included in models (**Table 5**). Evidence of interaction was seen, however, with bacon consumption and both age ($P_{interaction}$ = 0.05) and BMI ($P_{interaction}$ = 0.10). Further explorations of effect modification by age and BMI are reported in **Table 5**. An increased risk of colorectal cancer [HR_{adj} = 1.40 (95% CI: 1.02–1.94)] was seen with every 25 g/day increase in processed meat intake for 55+-year-old women, but not in younger women. Similarly, breakfast sausage consumption was associated with colorectal cancer in older women. Alternatively, bacon consumption examined continuously and in the highest tertile of exposure were associated with higher risk of colorectal cancer in younger participants only (<55 years old). When stratifying by BMI, higher consumption of bacon and breakfast sausage was positively associated with risk of colorectal cancer in obese women, but not normal or overweight women. We also observed a positive exposure–response trend by tertile of processed meat consumption in obese (P_{trend} = 0.03) but not nonobese women.

When stratifying by anatomic tumor subtype, we saw an increased risk in colon cancer for continuous measures of bacon and breakfast sausage consumption (Supplementary Table S1). In final models, elevated HRs for rectal cancer were also seen with bacon and breakfast sausages, although the number of rectal cancer cases was small (N = 30). When analyses were restricted to medically confirmed colorectal cancer cases only, associations tended to be stronger (Supplementary Table S2). We did not see any change in effect estimates when mutually adjusting for aggregate meat types or processed meat products (Supplementary Table S3), or when organ meat was adjusted for in unprocessed red meat models [Q4 vs. Q1 HR_{adj} = 1.02 (95% CI: 0.66–1.58)]. Results examining shellfish consumption alone did not differ from all seafood [shellfish consumption, Q4 vs. Q1 HR_{adj} = 0.87 (95% CI: 0.60–1.29)]. Results for analyses with additional exclusion criteria are in Supplementary Table S4. Estimates did not substantially differ when excluding participants reporting previous cancers at baseline (not including non-melanoma skin cancers). No differences were seen when excluding participants with a family history of colorectal cancer. When excluding cases with diagnoses that occurred within 1 and 2 years after baseline, estimates were somewhat attenuated and less precise; however, the patterns of elevated risk estimates remained. No differences in results were seen when other methods were used to restrict extreme values of daily caloric intake. When meat intake was energy adjusted using the nutrient density method, we found the magnitude and significance of results were generally similar for most meat variables (Supplementary Table S5). Of note, the HR_{adj} for the highest quartile of unprocessed red meat was elevated but remained nonsignificant [HR_{adj} = 1.17 (95% CI: 0.78–1.77)], and the

Table 4. Multivariable HR_{adj} for the association between meat cooking practices, doneness, and risk of colorectal cancer for specific red meat products[a].

		Cases	HR_{adj}[b] (95% CI)
Preferred meat cooking method by meat product			
Steak	Don't eat steak	11	1.0
	Pan-fried	16	2.09 (0.96–4.53)
	Oven broiled	29	1.69 (0.84–3.40)
	Grilled or barbequed	151	**2.23 (1.20–4.14)**
Hamburger	Don't eat hamburgers or cheeseburgers	9	1.0
	Pan-fried	39	1.63 (0.79–3.40)
	Oven broiled	11	1.55 (0.64–3.75)
	Grilled or barbequed	144	**1.98 (1.00–3.91)**
Pork chops	Don't eat pork chops	30	1.0
	Pan-fried	58	1.19 (0.76–1.86)
	Baked	59	1.17 (0.74–1.80)
	Oven broiled	17	1.11 (0.61–2.03)
	Grilled or barbequed	44	1.13 (0.70–1.80)
Preferred meat doneness by meat product			
Steak	Don't eat steak	12	1.0
	Rare or medium rare	85	**2.34 (1.27–4.32)**
	Medium or medium-well	86	1.52 (0.83–2.79)
	Well done, very well done, or charred	25	1.55 (0.77–3.11)
Hamburger	Don't eat hamburgers or cheeseburgers	9	1.0
	Rare or medium rare	22	**2.27 (1.04–4.95)**
	Medium or medium-well	89	1.77 (0.88–3.52)
	Well done, very well done, or charred	88	1.84 (0.92–3.68)
Pork chops	Don't eat pork chops	28	1.0
	Just until done	47	1.31 (0.82–2.10)
	Well done	97	1.06 (0.69–1.62)
	Very well done or charred	35	1.50 (0.91–2.49)
Bacon or sausage	Don't eat bacon or sausages	17	1.0
	Just until done	23	1.67 (0.89–3.14)
	Well done, crisp, or charred	168	1.32 (0.80–2.18)
Grilled and doneness preferences combined, by meat product			
Steak: doneness and grilled combined	Don't eat steak	12	1.0
	Rare or medium rare	62	**2.58 (1.37–4.86)**
	Medium or medium-well	73	**1.93 (1.04–3.60)**
	Well done, very well done, or charred	16	1.75 (0.82–3.74)
Hamburgers: doneness and grilled combined	Don't eat hamburgers or cheeseburgers	9	1.0
	Rare or medium rare	17	**2.62 (1.16–5.93)**
	Medium or medium-well	71	2.01 (0.99–4.06)
	Well done, very well done, or charred	59	1.97 (0.97–4.00)

Note: Significant ($P < 0.05$) values are bolded.
[a]For each model, the reference category includes participants who reported eating red meat but not the specific meat product or using the specific cooking method under evaluation.
[b]Model adjusted for total calories (kcal/day, continuous), BMI (kg/m^2, continuous), highest educational attainment (high school or less, some college, Bachelor's degree and above), physical activity (MET-h/wk, continuous), race/ethnicity (non-Hispanic White, non-Hispanic Black, Hispanic/other), and family history of colorectal cancer (yes/no).

HR_{adj} in the highest quartile of bacon consumption attenuated [HR_{adj} = 1.22 (95% CI: 0.81–1.82)], and no exposure–response trend was seen (P_{trend} = 0.32).

Discussion

In our prospective analysis of U.S. women, processed meat consumption was positively associated with increased colorectal cancer incidence. Our findings are consistent with authoritative hazard assessments concluding processed meat is carcinogenic to humans (2, 3). Despite bacon and breakfast sausages having the lowest median intake compared with other specific processed meat products in our study population, the strength of the association we saw was more pronounced for both bacon and breakfast sausages, than for lunch meats, hot dogs, or dinner sausages. Evidence of positive (13) and null (14, 15) associations with individual meat products (i.e., bacon, sausages, and hamburgers) and risk of colorectal cancer or colorectal adenomas have been seen.

Compared with the U.S. women population, our study population consumed, on average, less red meat (28.4 g/day) than women in NHANES 2003–2004 (52.8 g/day; ref. 16). We cannot definitively explain why we saw lower meat consumption relative to other cohorts (14, 17, 18). Evidence suggest dietary patterns do not change following diagnosis of sister's breast cancer (19, 20). Possible alternative explanations may include differences in consumption by population demographics or changes in dietary trends. Meat is an

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Table 5. Multivariable HR_{adj}[a] for the association between processed meat consumption and risk of colorectal cancer by age and BMI status at baseline.

		Age at baseline[c]				BMI status[d,e]					
		< 55 years old (N = 22,950)		55+ years old (N = 25,756)		Normal (N = 18,312)		Overweight (N = 15,493)		Obese (N = 14,346)	
		N	HR_{adj} (95% CI)	N	HR_{adj} (95% CI)	N	HR_{adj} (95% CI)	N	HR_{adj} (95% CI)	N	HR_{adj} (95% CI)
Processed meat	Continuous (per 25 g/day)	62	1.07 (0.67–1.72)	148	**1.40 (1.02–1.94)**	62	1.03 (0.56–1.88)	76	1.35 (0.87–2.10)	70	1.35 (0.89–2.04)
	Tertile 1 (4.96 g/day)	15	1.0	52	1.0	22	1.0	28	1.0	16	1.0
	Tertile 2 (11.20 g/day)	20	1.05 (0.53–2.07)	42	0.94 (0.62–1.42)	28	1.77 (1.00–3.14)	20	0.72 (0.40–1.30)	14	0.70 (0.32–1.38)
	Tertile 3 (24.58 g/day)	27	1.12 (0.56–2.25)	54	1.41 (0.92–2.17)	12	0.99 (0.47–2.11)	28	1.15 (0.64–2.07)	40	1.58 (0.83–3.01)
	P_{trend}[b]		0.81		0.07		0.92		0.46		**0.03**
Ham, baloney, lunch meat	Continuous (per 25 g/day)	62	0.97 (0.54–1.75)	148	1.30 (0.88–1.93)	62	0.98 (0.48–2.00)	76	1.28 (0.75–2.16)	70	1.26 (0.75–2.10)
	Tertile 1 (0.46 g/day)	10	1.0	63	1.0	27	1.0	24	1.0	21	1.0
	Tertile 2 (2.15 g/day)	26	1.76 (0.85–3.67)	43	0.76 (0.51–1.12)	14	0.61 (0.32–1.17)	31	1.26 (0.73–2.15)	24	0.89 (0.49–1.60)
	Tertile 3 (16.00 g/day)	26	2.00 (0.94–4.25)	42	1.11 (0.74–1.67)	21	1.35 (0.75–2.45)	21	1.22 (0.66–2.24)	25	1.16 (0.63–2.15)
	P_{trend}[b]		0.22		0.32		0.10		0.82		0.40
Hot dogs, dinner sausages	Continuous (per 10 g/day)	62	0.85 (0.43–1.72)	148	0.97 (0.60–1.58)	62	0.82 (0.27–2.47)	76	0.85 (0.38–1.90)	70	0.96 (0.57–1.63)
	Tertile 1 (0.74 g/day)	25	1.0	62	1.0	27	1.0	31	1.0	28	1.0
	Tertile 2 (1.48 g/day)	12	0.73 (0.37–1.47)	35	1.02 (0.68–1.55)	20	1.59 (0.89–2.85)	21	1.18 (0.68–2.06)	7	0.31 (0.14–0.71)
	Tertile 3 (3.46 g/day)	25	1.06 (0.59–1.90)	50	1.34 (0.91–1.98)	15	1.42 (0.75–2.72)	24	1.21 (0.70–2.10)	35	1.02 (0.61–1.71)
	P_{trend}[b]		0.71		0.11		0.20		0.59		0.38
Bacon	Continuous (per 10 g/day)	62	**3.72 (1.79–7.76)**	148	1.10 (0.40–3.06)	62	0.94 (0.13–6.74)	76	1.94 (0.61–6.17)	70	**2.67 (1.16–6.15)**
	Tertile 1 (0.11 g/day)	12	1.0	50	1.0	23	1.0	26	1.0	12	1.0
	Tertile 2 (0.43 g/day)	14	1.06 (0.49–2.30)	52	1.28 (0.86–1.89)	20	1.23 (0.67–2.25)	26	1.13 (0.65–1.95)	20	1.41 (0.69–2.91)
	Tertile 3 (1.83 g/day)	36	**2.63 (1.34–5.14)**	46	1.10 (0.73–1.66)	19	1.49 (0.80–2.76)	24	0.99 (0.56–1.74)	38	**2.17 (1.12–4.19)**
	P_{trend}[b]		**<0.001**		0.84		0.15		0.80		**0.01**
Breakfast sausages	Continuous (per 10 g/day)	62	1.31 (0.82–2.11)	148	**1.54 (1.15–2.06)**	62	1.51 (0.71–3.20)	76	1.31 (0.78–2.20)	70	**1.46 (1.04–2.05)**
	Tertile 1 (0.00 g/day)	18	1.0	49	1.0	29	1.0	23	1.0	15	1.0
	Tertile 2 (0.89 g/day)	10	0.51 (0.23–1.11)	46	1.07 (0.72–1.61)	20	0.88 (0.50–1.56)	23	1.06 (0.59–1.89)	12	0.71 (0.33–1.52)
	Tertile 3 (2.08 g/day)	34	1.57 (0.87–2.83)	53	1.48 (0.99–2.21)	13	0.89 (0.46–1.73)	30	1.59 (0.91–2.77)	43	**2.03 (1.11–3.70)**
	P_{trend}[b]		0.05		0.05		0.65		0.07		**0.003**

Note: Significant ($P < 0.05$) values are bolded.

[a]For age, model adjusted for total calories (kcal/day, continuous), BMI (kg/m^2, continuous), highest educational attainment (high school or less, some college, Bachelor's degree and above), physical activity (MET-h/wk, continuous), race/ethnicity (non-Hispanic White, non-Hispanic Black, Hispanic/other), and family history of colorectal cancer (yes/no); for BMI, model adjusted for total calories (kcal/day, continuous), highest educational attainment (high school or less, some college, Bachelor's degree and above), physical activity (MET-h/wk, continuous), race/ethnicity (non-Hispanic White, Non-Hispanic Black, Hispanic/other), and family history of colorectal cancer (yes/no).

[b]P_{trend} calculated using assigning the median value of each tertile.

[c]Test for interaction: age and red meat ($P = 0.30$); age and processed meat ($P = 0.31$); age and hot dogs/dinner sausages ($P = 0.36$); age and ham/baloney/lunch meat ($P = 0.72$); age and bacon ($P = 0.05$); age and breakfast sausage ($P = 0.24$).

[d]Test for interaction: BMI and red meat ($P = 0.71$); BMI and processed meat ($P = 0.68$); BMI and hot dogs/dinner sausages ($P = 0.97$); BMI and ham/baloney/lunch meat ($P = 0.29$); BMI and bacon ($P = 0.10$); BMI and breakfast sausage ($P = 0.24$).

[e]Normal BMI: 18.5–24.9; overweight BMI: 25.0–29.9; obese BMI: ≥ 30.0 [underweight (BMI < 18.5, $N = 541$ noncases, 2 cases) excluded].

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important source of protein, providing approximately 40% of daily protein and 15% of daily energy intake in the United States. Aside from protein, red meat is also a source of micronutrients including iron, zinc, and vitamin B12, as well as essential fatty acids such as the polyunsaturated fatty acids ω-3 α-linolenic acid and ω-6 linoleic acid. Meat can also provide large amounts of certain types of fat, specifically saturated and trans fats, and cooked and processed meats can produce known or suspected human mutagens, including endogenous N-nitroso compounds (NOC) from nitrates and nitrites used in curing, and formation of heterocyclic amines (HCA) and polycyclic aromatic hydrocarbons (PAH) from cooking at high temperatures (21). Other constituents of red meat, such as heme iron, may also play a role in cancer development (22). On the basis of studies examining mutagenic components of meat subtypes and specific meat products, levels of carcinogenic agents, including HCAs (23, 24) and heme iron (25), can vary.

Despite adjustment for caloric intake and physical activity, the association between consumption of certain processed meat products and risk of colorectal cancer was strong in obese women. Processed meat is high in saturated fat, trans fat and cholesterol, and has been found to be associated with an increased risk of obesity, diabetes mellitus, and cardiovascular disease. Excess weight may play a role modifying the effect of meat consumption on cancer via inflammation (26). Considering the causal pathway, it remains unclear whether obesity should be treated as a confounder, mediator, or both.

Surprisingly, we found younger women have an increased risk with higher bacon consumption, while older women are at an increased risk with higher breakfast sausage and overall processed meat consumption. Our observed differences in age-stratified models for specific processed meat products may be due to changing consumption patterns or changes in mutagenic constituents of these meat products over time; indeed, identifying risk factors by age at diagnosis has become a research priority given increasing rates in those under age 55 (27).

Although we did not find an association in the highest quartile of unprocessed red meat consumption and colorectal cancer, we saw an increased risk associated with cooking preference for specific red meat products. For red meat consumption overall, it is possible our inconsistent findings with IARC (2) and WCRF/AICR (3) conclusions are due to lower reported unprocessed red meat intake in our unique study population of higher socioeconomic status and predominantly non-Hispanic white women in the United States with a sister who was diagnosed with breast cancer. Higher risk estimates have been noted in men compared with women (3, 28) and in European cohorts compared with North American cohorts (3). A recent large U.K. study found a null risk for colorectal cancer in women, but not men, regardless of amount of red or processed meat consumed (29).

An increased risk was seen by high temperature cooking techniques for certain red meat products, including preference of grilling or barbecuing steak and hamburgers. Higher PAH concentrations can be produced when meats are directly exposed to a flame. Furthermore, steak and hamburgers were found to have the highest heme iron concentrations (25), which can serve as a catalyst for endogenous NOC formation. We also found generally similar associations by doneness preference for steak, hamburgers, pork chops, and bacon or sausages. Doneness level has been found to not significantly change heme iron concentrations (25), but does increase HCA levels (23, 24). Pouzou and colleagues (30) found the highest estimated concentrations of eight PAHs in beef (compared with other subtypes of red meat) and by barbecuing meat. Our significant findings for rare meat preference as well may be a result of PAH formation when meat is seared on open flame, or possibly *E. coli* and other pathogens inducing endogenous NOC formation (4). Because rare meat, including steak and hamburgers, is likely being grilled or barbecued (and therefore, being exposed to high heat and a direct flame), PAHs are still being produced.

Our study has a number of strengths and limitations. Baseline dietary and cooking method questionnaires allowed for assessment of detailed consumption patterns. Compared with other prospective cohort studies conducted in the 1980s and 1990s, the Sister Study's later enrollment period (2003–2009) captures more recent food consumption patterns in U.S. women. Furthermore, we were able to examine specific meat products and cooking methods in a group of women who reported eating any meat. We successfully followed a large number of study participants over a median of 8.7 years of follow-up, with median time from enrollment to diagnosis of 4.8 years for cases. The prospective study design avoided the possibility of recall bias, which is a large concern in case–control investigations of this topic.

Nonetheless, the number of colorectal cancer cases was small, limiting our statistical power and inhibiting our ability to further stratify by colon subtypes (e.g., proximal, distal). Stratification by tumor type, also resulted in a small sample size for rectal cancer cases, making interpretation of results difficult. Given that cohort participants were also generally affluent non-Hispanic white women, results are less generalizable to the U.S. population. Lower meat consumption is seen with increasing age and education (16). Our reliance on a single baseline evaluation of meat intake does not allow us to examine potential changes in meat consumption over time. Furthermore, the possibility of exposure misclassification is always present when using an FFQ. We also note that the cooking practices module was not accompanied by visual aids to help distinguish cooking method or level of doneness. In addition, broader cooking technique categorizations may mask important variations in specific cooking practices, and unreported practices including use of marinades may influence the carcinogenic potential of certain meats. For example, grilling and barbecuing were grouped together based on the questionnaire, but temperature considerations for barbecuing may vary substantially by U.S. region and ethnic group.

In conclusion, we found that processed meat consumption, including bacon and breakfast sausages, is associated with a higher risk of colorectal cancer in U.S. women, further confirming results from previous studies. Specific unprocessed red meat products, including hamburgers and steaks, cooked by grilling or barbecuing are also associated with elevated risk of colorectal cancer. The development of prevention strategies for colorectal cancer should account for these important risk factors.

Disclosure of Potential Conflicts of Interest

No potential conflicts of interest were disclosed.

Authors' Contributions

Conception and design: S.S. Mehta, W.D. Arroyave, W.A. Boyd
Development of methodology: S.S. Mehta, W.D. Arroyave, Y.-M.M. Park
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