Associations of processed meat and unprocessed red meat intake with incident diabetes: the Strong Heart Family Study[1–4]

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ABSTRACT

Background: Fifty percent of American Indians (AIs) develop diabetes by age 55 y. Whether processed meat is associated with the risk of diabetes in AIs, a rural population with a high intake of processed meat (eg, canned meats in general, referred to as "spam") and a high rate of diabetes, is unknown.

Objective: We examined the associations of usual intake of processed meat with incident diabetes in AIs.

Design: This prospective cohort study included AI participants from the Strong Heart Family Study who were free of diabetes and cardiovascular disease at baseline and who participated in a 5-y follow-up examination (n = 2001). Dietary intake was ascertained by using a Block food-frequency questionnaire at baseline. Incident diabetes was defined on the basis of 2003 American Diabetes Association criteria. Generalized estimating equations were used to examine the associations of dietary intake with incident diabetes.

Results: We identified 243 incident cases of diabetes. In a comparison of upper and lower quartiles, intake of processed meat was associated with a higher risk of incident diabetes (OR: 1.63; 95% CI: 1.21, 2.63), after adjustment for potential confounders. The relation was particularly strong for spam (OR for the comparison of upper and lower quartiles: 2.06; 95% CI: 1.30, 3.27). Intake of unprocessed red meat was not associated with incident diabetes (OR for the comparison of upper and lower quartiles: 0.90; 95% CI: 0.59, 1.37).

Conclusion: The consumption of processed meat, such as spam, but not unprocessed red meat, was associated with higher risk of diabetes in AIs, a rural population at high risk of diabetes and with limited access to healthy foods. *Am J Clin Nutr* 2012;95:752–8.

INTRODUCTION

Recent studies indicate that the health effects of processed meat and unprocessed red meat on diabetes risk may differ (1–4). Prior studies have not examined the associations of processed meat or unprocessed red meat intake among populations with exceedingly high rates of obesity and diabetes. Often, these populations have limited access to healthy foods. For example, for AIs[5] living in rural areas or reservations, dietary choices are influenced by foods available at local convenience stores or through the USDA commodity foods assistance program, such as "spam" (canned meats in general) (5–7). Thus, they provide an excellent opportunity to better understand the associations of processed meat and unprocessed red meat intake on diabetes risk.

The purpose of this study was to examine the associations of usual intake of processed meat and unprocessed red meat with incident diabetes among AIs from 13 communities who participated in the SHFS, a population-based cohort study with 2 examinations over an 8-y period. The SHFS offers a unique opportunity to assess the relation of processed meat and unprocessed red meat intake with incident diabetes in an underserved population with a high risk of obesity and diabetes.

SUBJECTS AND METHODS

Setting and study population

The SHFS is a population-based longitudinal study of the genetics and risk factors for cardiovascular disease in 13 AI communities in Arizona, North Dakota, South Dakota, and Oklahoma. The SHFS included 2 examinations, a baseline examination in 2001–2003 and a follow-up examination in 2007–2009. Details of the study design have been described previously (8). Briefly, 1468 men and 2197 women from 96 large families (mean number of participants per family: 21; range: 1–57) completed a baseline examination. In 2007–2009, 91% of the participants who participated in the baseline examination had a follow-up exam. The institutional review board (Rapid City, SD; Phoenix, AZ; Oklahoma City, OK) and Indian Health Services office for each participating tribe approved the study, and written informed consent was obtained from all participants at enrollment.

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[5] Abbreviations used: AI, American Indian; FFQ, food-frequency questionnaire; GEE, generalized estimating equation; SHFS, Strong Heart Family Study.

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For the current investigation, we excluded SHFS participants who had diabetes at the baseline examination in 2001–2003 (n = 829) and those without a follow-up examination in 2007–2009 (n = 278). There were no differences in the baseline characteristics of participants who did and did not participate in the follow-up examination. In addition, we excluded those with a history of myocardial infarction (n = 72), stroke (n = 25), heart failure (n = 13), or who were pregnant at the baseline exam (n = 5) because these conditions may influence diet and diabetes risk. Participants missing baseline glucose measures (n = 21) or family information (n = 7) or who were aged $<$18 y or $\geq$75 y (n = 135) were excluded. Finally, participants with unreliable dietary data were excluded. This included participants who skipped $>$10% of the questions on the dietary assessment instrument (n = 159) or who reported having extreme caloric intakes [intakes of $<$600 kcal/d (n = 36) or $>$6000 kcal/d (n = 57) for women and $<$600 or $>$8000 kcal/d (n = 27) for men were used as thresholds, as in previous Strong Heart Study analyses (9)]. The remaining 2001 persons comprised the study population for the current analysis.

Data collection

The baseline examination included a standardized personal interview, physical examination, medication review, laboratory testing, and a 1-wk pedometer log. Information regarding medical conditions, education, smoking, alcohol consumption, and dietary intake during the past year was collected at the personal interview (8).

Anthropometric measures were obtained while the participant was wearing light clothing and no shoes. Body weight was measured by using a Tanita BWB-800-5 digital scale (Tanita Corp), and height was measured by using a vertical mounted ruler. BMI was calculated as body weight divided by height squared (kg/m^2). Waist circumference was measured at the umbilicus while the participant was in a supine position (8).

Blood samples were collected after a 12-h overnight fast and were stored at −70°C. Plasma glucose was measured by using enzymatic methods, and insulin was measured by using a modified version of the Morgan and Lazarow radioimmunoassay test (10). LDL and HDL cholesterol were isolated by ultracentrifugation, as described previously (10).

Dietary assessment

An interviewer-administered Block 119-item FFQ was used to measure usual food intake during the past year. The Block FFQ is one of the most widely used food questionnaires, and it has demonstrated reliability and validity (11–14). Serving sizes, described as standard units (eg, 1 banana, 2 eggs, etc) or standard volume/weight portions, were assessed by using photographs of various portions as visual aids. Each participant was asked how often, on average, a particular food was consumed during the past year. The quantity was assessed by using measures of consumption frequency (ie, seasonally, never, a few times per year, once per month, 2–3 times/mo, once per week, twice per week, 2–3 times/wk, 5–6 times/wk, daily) and adjusted for portion size (small, medium, or large). In addition to food items on the standard Block FFQ, participants were asked additional questions about the frequency of consumption and the portion size of foods commonly consumed among AIs such as *menudo*, *pozole*, *guysava*, red or green chili, Indian taco, fry bread, corn tortilla, flour tortilla, and "spam" (a term that refers to canned meats, usually a combination of beef or pork shoulder, salt, sodium nitrate, potato starch, and water, that are available from several producers in the United States). Spam has a long shelf life and does not require refrigeration. Spam is provided free of charge to many AIs on reservations throughout the United States as part of the USDA food assistance/commodity foods program or can be purchased at local shops. For certain ethnic groups, the inclusion of an ethnic foods section on the FFQ contributes considerably to group mean nutrient estimates (15), thus including them on the questionnaire may have produced more accurate nutrient (and energy intake) estimates.

Average daily energy and macronutrient intakes were calculated for each study participant by using the Block database (Block Dietary Systems). To obtain measures of average daily energy and nutrient intake, the frequency response for each food on the FFQ and AI supplementary foods questionnaire was multiplied by the nutrient content of the documented portion size of the food, then summed for all foods (16).

Diabetes assessment

Incidence of diabetes was defined on the basis of 2003 American Diabetes Association criteria (17). Diabetes was defined by use of insulin or oral antidiabetic medication or by a fasting plasma glucose concentration $\geq$126 mg/dL at the follow-up exam in 2007–2009. Because type 1 diabetes is rare in AI populations and all SHFS participants were $\geq$18 y of age at baseline, we assumed that all new occurrences of diabetes were type 2.

Statistical analyses

For this report, we were most interested in processed meat (eg, breakfast sausage, spam, hot dogs, and lunch meat) and unprocessed red meat (eg, pork chops, pork roast, dinner ham, veal, lamb, deer, ribs, hamburger, cheeseburger, roast beef, steak, liver) and as primary dietary exposures. Similar to previous studies (1), we considered 50 g (1.8 oz) and 100 g (3.5 oz) as one serving of processed meat and unprocessed red meat, respectively.

GEE with an independence working correlation structure and robust SEs was used to examine whether processed meat or unprocessed red meat was associated with the risk of diabetes. Given the family-based sampling, GEE was used to address potential familial correlation within the data. All statistical analyses were conducted by using STATA version 9.0 (Stata Corp).

Dietary factors were examined both continuously and categorically with the use of quartiles. Each exposure is expressed with the use of nutrient density models. Presenting nutrient intakes as nutrient densities has been shown to correct for over- or underreporting of intake on the FFQ (18). Under a logistic model, we computed the OR and 95% CI for developing diabetes using GEE. For each categorical analysis, ORs (95% CIs) were calculated by using participants in the lowest category of intake as the referent group, after adjustment for confounding factors. To avoid false associations of nutrients with disease risk due to confounding by total energy intake, all analyses adjusted for total energy intake (18).

Four levels of adjustment were used to examine the associations of processed meat or unprocessed red meat with incident diabetes. Model 1 (minimally adjusted model) adjusted for age,

sex, site, and total caloric intake. The second model additionally adjusted for a priori confounders, including education, smoking, alcohol use, family history of diabetes, and pedometer-determined physical activity levels (steps/d). Because other dietary factors may confound the association of the nutrient or food of interest and incident diabetes, we also adjusted for other dietary factors including glycemic load and fiber from grains in a third model. In model 4, we additionally adjusted for BMI to better determine whether obesity might confound or mediate the relation of meat intake and incident diabetes (19–21).

We examined the potential interaction of each dietary factor with sex, site, age, BMI, and pedometer-determined steps/d to investigate whether these factors modified the ORs that measured associations of these exposures with incident diabetes (22–25). To test the statistical significance of the interaction, we used Wald tests.

RESULTS

Among the 2001 SHFS participants who comprised the analytic cohort for this report, ~61% were female and the median age at baseline examination was 35.0 y (range: 18.0–74.9 y). The consumption of processed meat and unprocessed red meat was high in the study population. Sixteen (0.8%) participants reported not consuming any processed meat in the past year, 260 (13.0%) consumed <1 serving/wk, 358 (17.9%) consumed 1–2 servings/wk, and 1367 (68.3%) consumed >2 servings processed meat/wk. For unprocessed red meat, 5 (0.2%) participants reported not consuming any unprocessed red meat during the past year, 184 (9.2%) consumed <1 serving/wk, 452 (22.6%) consumed 1–2 servings/wk, and 1360 (68.0%) consumed >2 servings unprocessed red meat/wk.

Baseline characteristics of the study participants according to quartile of total processed meat intake are shown in **Table 1**. Participants who reported higher intakes of processed meat were younger, less educated, more likely to be male, had larger waist circumferences, and higher BMI than did participants who reported diets lower in processed meat. In addition, participants who reported diets higher in processed meat had lower HDL cholesterol and reported a higher percentage of calories from total fat and fewer calories from carbohydrates than did those who reported diets lower in processed meat. Similar to total processed meat, participants who reported diets higher in spam were younger, less educated, more likely to be male, had larger waist circumferences, had higher BMI, had lower HDL cholesterol, and reported diets higher in saturated fat and lower in carbohydrates than did participants who reported diets lower in spam (data not shown). Participants who reported diets higher in unprocessed red meat were more likely to be male and had a higher percentage of calories from total fat and fewer calories from carbohydrates compared with participants whose diets were lower in unprocessed red meat. On the other hand, there were no differences in age, BMI, waist circumference, or HDL cholesterol according to intake of unprocessed red meat; and participants who consumed diets high in unprocessed red meat had a higher educational level than did participants who consumed diets lower in unprocessed red meat (data not shown).

TABLE 1
Baseline characteristics of study participants according to quartile of processed meat intake

	Processed meat intake (g/1000 kcal)			
Characteristics	<6.5	6.5 to <11.4	11.4 to <18.2	≥18.2
Age (y)	36.4 ± 16.0[1]	36.7 ± 14.3	34.1 ± 13.7	32.9 ± 12.8
Female (%)	76.6	63.6	53.2	50.8
Waist circumference (cm)	97.4 ± 16.0	101.6 ± 17.8	103.5 ± 18.5	104.5 ± 18.4
BMI (kg/m^2)	30.2 ± 6.9	31.6 ± 7.5	32.1 ± 7.8	32.3 ± 8.2
SBP[2] (mm Hg)	119.0 ± 15.2	120.3 ± 14.1	120.2 ± 14.3	120.7 ± 15.2
Insulin (μU/mL)	15.6 ± 17.8	15.3 ± 11.4	16.1 ± 14.8	16.8 ± 13.8
Fasting glucose (mg/dL)	92.0 ± 10.4	94.4 ± 10.1	94.2 ± 10.8	94.7 ± 10.5
HDL cholesterol (mg/dL)	53.5 ± 14.4	52.2 ± 15.1	51.1 ± 14.7	50.5 ± 14.0
Education (y)	12.4 ± 2.3	12.2 ± 2.2	11.7 ± 2.3	11.4 ± 2.1
Steps/d	6394.4 ± 3916.6	5854.9 ± 3652.6	6433.2 ± 4354.8	6195.2 ± 4043.2
Total fat (% of energy)	36.1 ± 7.9	37.9 ± 6.5	38.8 ± 6.1	40.8 ± 5.7
Saturated fat (% of energy)	10.6 ± 2.4	11.3 ± 1.9	11.7 ± 1.9	12.5 ± 1.8
Carbohydrates (% of energy)	52.2 ± 10.0	49.6 ± 7.8	47.7 ± 7.4	45.2 ± 7.0
Unprocessed red meat (g/1000 kcal)	21.8 ± 19.7	24.7 ± 16.5	22.3 ± 14.7	22.3 ± 14.4
Total dietary fiber (g/1000 kcal)	7.9 ± 3.0	7.4 ± 2.4	7.2 ± 2.0	6.7 ± 1.9
Fruit (servings/d)	1.1 ± 1.0	0.9 ± 0.8	0.9 ± 0.7	0.9 ± 0.7
Vegetables (servings/d)	2.6 ± 2.3	2.5 ± 2.0	2.6 ± 1.9	2.5 ± 2.3
Added sugar (mL)	119.5 ± 86.5	121.0 ± 84.5	123.0 ± 78.5	118.5 ± 79.5
Sweetened-beverage intake (%)				
<1 time/mo	10	7.7	5.8	4.0
1–8 times/mo	30.5	27.8	26.6	21.6
3–6 times/wk	24.0	34.8	41.8	39.4
Every day	35.5	29.8	25.8	25.0
Smoking (%)				
Never	47.1	43.8	42.8	40.4
Current	30.9	35.1	37.0	40.2

[1] Mean ± SD (all such values).
[2] SBP, systolic blood pressure.

TABLE 2
ORs (95% CIs) of diabetes according to processed meat intake[1]

	Quartile				
	1	2	3	4	*P*-trend
Processed meat intake (g/1000 kcal)[2]	<6.5	6.5 to <11.4	11.4 to <18.2	≥18.2	
Median intake (IQR)	3.71 (2.27, 5.03)	8.83 (7.57, 10.1)	14.5 (12.9, 15.9)	23.6 (20.8, 29.2)	
No. of cases	39	61	79	64	
Total no. at risk	501	500	500	500	
Model					
Minimally adjusted[3]	1.00	1.61 (1.03, 2.54)	2.01 (1.31, 3.09)	1.63 (1.04, 2.54)	0.03
Multivariate[4]	1.00	1.53 (0.96, 2.44)	1.96 (1.25, 3.06)	1.55 (0.97, 2.47)	0.04
Dietary factors[5]	1.00	1.56 (0.97, 2.49)	2.03 (1.28, 3.20)	1.63 (1.21, 2.63)	0.03
BMI[6]	1.00	1.45 (0.89, 2.35)	1.77 (1.10, 2.85)	1.35 (0.81, 2.25)	0.17
Spam intake (g/1000 kcal)	0	0.10 to <1.14	1.14 to <3.10	≥3.10	
Median intake (IQR)	0 (0, 0)	0.71 (0.51, 0.91)	1.83 (1.43, 2.35)	5.88 (4.15, 9.44)	
No. of cases	44	48	66	85	
Total no. at risk	579	422	500	500	
Model					
Minimally adjusted[3]	1.00	1.27 (0.83, 1.95)	1.49 (0.90, 2.47)	1.95 (1.24, 3.07)	0.001
Multivariate[4]	1.00	1.31 (0.83, 2.06)	1.52 (0.91, 2.52)	1.99 (1.25, 3.17)	0.001
Dietary factors[5]	1.00	1.31 (0.83, 2.07)	1.54 (0.92, 2.56)	2.06 (1.30, 3.27)	0.001
BMI[6]	1.00	1.37 (0.87, 2.15)	1.40 (0.82, 2.36)	1.86 (1.17, 2.95)	0.01
Breakfast sausage intake (g/1000 kcal)	<0.74	0.74 to <2.08	2.08 to <4.57	4.57+	
Median intake (IQR)	0.31 (0, 0.52)	1.33 (1.02, 1.69)	3.02 (2.48, 3.65)	7.42 (5.71, 10.3)	
No. of cases	55	57	70	61	
Total no. at risk	501	500	500	500	
Model					
Minimally adjusted[3]	1.00	1.10 (0.75, 1.61)	1.42 (1.01, 2.01)	1.26 (0.86, 1.84)	0.15
Multivariate[4]	1.00	0.99 (0.67, 1.44)	1.30 (0.91, 1.86)	1.22 (0.82, 1.82)	0.21
Dietary factors[5]	1.00	1.00 (0.68, 1.46)	1.32 (0.93, 1.88)	1.24 (0.83, 1.86)	0.18
BMI[6]	1.00	0.87 (0.59, 1.28)	1.18 (0.80, 1.73)	1.09 (0.72, 2.66)	0.40
Hot dog intake (g/1000 kcal)	<0.90	0.90 to <2.06	2.06 to <4.13	≥4.13	
Median intake (IQR)	0.27 (0, 0.62)	1.45 (1.17, 1.76)	2.90 (2.42, 3.46)	6.57 (5.12, 10.0)	
No. of cases	56	67	62	58	
Total no. at risk	501	500	500	500	
Model					
Minimally adjusted[3]	1.00	1.20 (0.82, 1.77)	1.11 (0.78, 1.58)	1.08 (0.73, 1.61)	0.82
Multivariate[4]	1.00	1.21 (0.78, 1.85)	1.10 (0.75, 1.61)	1.06 (0.69, 1.63)	0.91
Dietary factors[5]	1.00	1.21 (0.79, 1.85)	1.11 (0.76, 1.62)	1.08 (0.70, 1.67)	0.83
BMI[6]	1.00	1.13 (0.74, 1.72)	0.97 (0.65, 1.44)	0.88 (0.56, 1.38)	0.43
Lunch meat intake (g/1000 kcal)	<0.92	0.92 to <2.51	2.51 to <5.57	≥5.57	
Median intake (IQR)	0 (0, 0.53)	1.61 (1.24, 2.03)	3.74 (3.13, 4.62)	8.61 (6.97, 11.7)	
No. of cases	54	64	52	73	
Total no. at risk	501	500	500	500	
Model					
Minimally adjusted[3]	1.00	1.16 (0.80, 1.68)	0.91 (0.63, 1.33)	1.39 (1.00, 1.95)	0.25
Multivariate[4]	1.00	1.11 (0.75, 1.62)	0.98 (0.67, 1.45)	1.42 (1.00, 2.01)	0.17
Dietary factors[5]	1.00	1.11 (0.75, 1.63)	1.00 (0.68, 1.46)	1.44 (1.01, 2.06)	0.14
BMI[6]	1.00	1.18 (0.80, 1.74)	0.91 (0.60, 1.37)	1.44 (0.98, 2.12)	0.20

[1] Generalized estimating equations were used to assess the association of processed meat intake with incident diabetes.
[2] Total processed meat includes spam, breakfast sausage, hot dogs, and lunch meat.
[3] Adjusted for age, sex, site, and total calories/d.
[4] Additionally adjusted for education, smoking, alcohol, family history of diabetes, and pedometer-determined physical activity.
[5] Additionally adjusted for fiber from grains and glycemic load.
[6] Additionally adjusted for BMI.

During 8 y of follow-up, diabetes developed in 243 of the 2001 study participants who were free of diabetes at baseline. Processed meat consumption was associated with higher odds of developing diabetes. In a comparison of each of the 3 upper quartiles with the lowest quartile of processed meat intake, the odds (95% CI) of developing diabetes were 1.56 (0.97, 2.49), 2.03 (1.28, 3.30), and 1.63 (1.21, 2.63), after adjustment for age, sex, site, total calories/d, education, smoking, alcohol use, family history of diabetes, steps/d, and dietary factors (*P*-trend = 0.03) (**Table 2**). The association of processed meats and diabetes appeared to be largely accounted for by spam intake. Compared with individuals in the lowest quartile of spam intake, the OR of diabetes among those in the highest quartile of intake was 2.06 (95% CI: 1.30, 3.27) after adjustment for potential confounders (*P*-trend < 0.001). Lunch meat was also associated with a higher risk of diabetes, but the magnitude of the OR was lower

TABLE 3
ORs (95% CIs) of diabetes according to unprocessed red meat intake[1]

	Quartile				
	1	2	3	4	*P*-trend
Total unprocessed red meat (g/1000 kcal)[2]	<11.5	11.5 to <18.7	18.7 to <29.6	≥29.6	
Median intake (IQR)	8.08 (5.60, 9.89)	14.7 (13.2, 16.8)	23.2 (20.5, 26.1)	40.3 (34.3, 50.3)	
No. of cases	67	66	55	55	
Total no. at risk	501	500	500	500	
Model					
Minimally adjusted[3]	1.00	1.13 (0.80, 1.58)	0.94 (0.64, 1.39)	0.94 (0.64, 1.40)	0.49
Multivariate[4]	1.00	1.13 (0.78, 1.65)	0.92 (0.61, 1.40)	0.87 (0.58, 1.32)	0.32
Dietary factors[5]	1.00	1.14 (0.78, 1.65)	0.93 (0.61, 1.42)	0.90 (0.59, 1.37)	0.42
BMI[6]	1.00	1.12 (0.77, 1.64)	0.83 (0.54, 1.27)	0.88 (0.57, 1.35)	0.31
Hamburger/cheeseburger (g/1000 kcal)	<2.59	2.59 to <5.19	5.19 to <9.59	≥9.59	
Median intake (IQR)	1.64 (1.12, 2.13)	3.72 (3.15, 4.43)	7.01 (6.13, 8.10)	15.1 (12.0, 21.3)	
No. of cases	71	60	64	48	
Total no. at risk	501	500	500	500	
Model					
Minimally adjusted[3]	1.00	0.92 (0.62,1.37)	1.06 (0.74, 1.51)	0.79 (0.52, 1.19)	0.35
Multivariate[4]	1.00	0.90 (0.60, 1.36)	1.02 (0.73, 1.43)	0.74 (0.47, 1.16)	0.24
Dietary factors[5]	1.00	0.90 (0.60, 1.35)	1.02 (0.73, 1.43)	0.75 (0.48, 1.18)	0.27
BMI[6]	1.00	0.80 (0.52, 1.25)	0.93 (0.65, 1.33)	0.69 (0.43, 1.12)	0.18
Beef (g/1000 kcal)	<2.53	2.53 to <5.33	5.33 to <10.1	≥10.1	
Median intake (IQR)	1.36 (0.59, 1.87)	3.76 (3.13, 4.49)	7.24 (6.26, 8.45)	15.6 (12.4, 22.7)	
No. of cases	61	53	71	58	
Total no. at risk	501	500	500	500	
Model					
Minimally adjusted[3]	1.00	0.86 (0.53, 1.40)	1.21 (0.80, 1.83)	0.99 (0.66, 1.48)	0.71
Multivariate[4]	1.00	0.88 (0.54, 1.44)	1.28 (0.83, 1.98)	1.00 (0.65, 1.55)	0.6
Dietary factors[5]	1.00	0.89 (0.54, 1.44)	1.31 (0.84, 2.02)	1.05 (0.67, 1.64)	0.47
BMI[6]	1.00	0.83 (0.51, 1.35)	1.16 (0.76, 1.78)	0.93 (0.60, 1.44)	0.9
Pork (g/1000 kcal)	<1.68	1.68 to <3.67	3.67 to <7.12	≥7.12	
Median intake (IQR)	0.96 (0.40, 1.29)	2.67 (2.09, 3.19)	5.13 (4.33, 6.66)	10.5 (8.55, 14.4)	
No. of cases	53	61	62	67	
Total no. at risk	501	500	500	500	
Model					
Minimally adjusted[3]	1.00	1.18 (0.79, 1.77)	1.27 (0.88, 1.83)	1.33 (0.92, 1.94)	0.17
Multivariate[4]	1.00	1.21 (0.81, 1.81)	1.28 (0.87, 1.90)	1.21 (0.80, 1.84)	0.37
Dietary factors[5]	1.00	1.23 (0.82, 1.84)	1.30 (0.88, 1.92)	1.26 (0.83, 1.92)	0.3
BMI[6]	1.00	1.25 (0.84, 1.86)	1.23 (0.82, 1.86)	1.18 (0.77, 1.82)	0.45

[1] Generalized estimating equations were used to assess the association of unprocessed red meat intake with incident diabetes. Beef includes beef roast, steak, or beef sandwiches. Pork includes pork chops, pork roast, or dinner ham.

[2] Total unprocessed red meat includes pork chops, pork roast, dinner ham, veal, lamb, deer, ribs, hamburger, cheeseburger, roast beef (beef roast, steak, or beef sandwiches), steak, and liver.

[3] Adjusted for age, sex, site, and total calories/d.

[4] Additionally adjusted for education, smoking, alcohol, family history of diabetes, and pedometer-determined physical activity.

[5] Additionally adjusted for fiber from grains and glycemic load.

[6] Additionally adjusted for BMI.

than that for spam, and there was no evidence of a dose-related trend. Comparing extreme quartiles of lunch meat intake, the OR for diabetes was 1.44 (95% CI: 1.01, 2.06), after multivariate adjustment. There was no significant association of breakfast sausage or hot dog intake with incident diabetes.

There was no significant association of unprocessed red meats and diabetes risk (**Table 3**). Sensitivity models that further adjusted for saturated fat, percentage of calories from carbohydrate, percentage of calories from protein, fruit and vegetable intake, sugar-sweetened beverage intake, diet quality (Alternative Healthy Eating Index), or other processed meats or unprocessed red meats, as appropriate, did not materially alter ORs. There were also no significant interactions between dietary factors and age, sex, site, BMI, or pedometer-determined steps/d when assessing diabetes risk. In addition, restricting analyses to participants <60 y of age produced similar results.

DISCUSSION

The results from this analysis indicate that intake of processed meats, particularly spam, is associated with a higher risk of developing diabetes. In contrast, unprocessed red meat intake was not associated with diabetes development. These data support the hypothesis that the health effects of meat intake on diabetes risk may differ by type of meat (ie, processed meat or unprocessed red meat).

Observed ORs for processed meats were partly attenuated after additional adjustment for baseline BMI. Such attenuation may be due to the independent effects of obesity on processed meat intake and diabetes. However, obesity may be in the causal pathway between processed meat intake and diabetes risk—that is, consuming a diet high in processed meats may cause weight gain and obesity, a risk factor for diabetes. As such, the model that adjusts for BMI may underestimate the effect of processed meat intake on diabetes risk.

These findings are consistent with several other prospective studies in whites and health professionals that showed a positive association of processed meats and incident diabetes (1–4, 26–29) and no association of unprocessed red meats and incident diabetes (1, 2, 4). In contrast, a large meta-analysis suggested that both processed meat and unprocessed red meat are associated with higher risk of diabetes; however, the association of processed meat and incident diabetes was considerably stronger than for unprocessed red meat (27). It is possible that our analysis was not adequately powered to detect a modest association of unprocessed red meat on diabetes risk.

Our results indicate that the magnitude of the relation of processed meat and diabetes is greatest for spam intake. Unlike spam, hot dogs, lunch meat, breakfast sausage, and the total processed meat categories comprise a heterogeneous mix of lean and nonlean meats (such as turkey or beef hot dogs, bologna or turkey breast lunch meat, and turkey or beef breakfast sausage). The lack of clear association (or dose-related trend) of non-spam processed meats on diabetes development may be due to the heterogeneity in the types of meats that comprise the non-spam processed meat categories or due to other measurement error/recall bias associated with the FFQ.

There are several possible biological mechanisms that might explain our findings. Processed meats are rich in additives and preservatives, including sodium nitrate, which could influence diabetes risk. Nitrosamines are present in processed meats at manufacturing or formed by interactions of amino acids and nitrates within the body. Nitrosamines have been shown to have a toxic effect on β cells and may promote the development of diabetes (30–34). Processed meats have higher amounts of nitrates than do unprocessed red meats (35), and this may, in part, explain the differences in diabetes risk for processed meats and unprocessed red meats. In addition, processed meats are also high in advanced glycation end products. Advanced glycation end products are formed in the heating and processing of meats and have been shown to influence inflammation and oxidative stress, both of which are risk factors for development of diabetes (30, 31, 36, 37).

Alternatively, it is possible that other unmeasured factors that influence both intake of processed meats and diabetes may have accounted for our results. Because many AI communities are located in isolated rural areas or on reservations, many people have limited access to healthy foods and rely on food items available at local convenience stores, including spam. In addition, the USDA food assistance program provides commodity foods to low-income AIs who reside on reservations in an effort to address national food insecurity; spam is a staple commodity food. Because the most disadvantaged participants may also have other unmeasured lifestyle characteristics for diabetes (eg, limited access to health care, inability to comply with medical advice), residual confounding may account for the association of processed meat/spam with diabetes development if processed meat intake is a marker for unmeasured socioeconomic disadvantage. More studies are needed to better understand this relation.

Our study has several strengths. Unlike most other studies in the literature that assessed the relation of meat intake and diabetes risk by using self-reported diabetes confirmed by a documented history of diabetes or a prescription for an antidiabetic medication (2–4, 26, 29), the SHFS had fasting plasma glucose measurements for all study participants at the baseline and follow-up examinations. Because 25% of all diabetes cases are undiagnosed (38), having fasting plasma glucose measures for all study participants reduces potential misclassification of diabetes status. In addition, to our knowledge, no published studies have analyzed the association of processed meat intake with incident diabetes among AIs, a population with a high intake of processed meat and a high burden of diabetes. Because the SHFS included supplementary questions that ascertained dietary intake of foods common in AI communities, such as spam, we may have been able to better estimate dietary intake for participants who consume these foods regularly.

This study also has several limitations. First, dietary assessment was based on a FFQ, and some participants might not have accurately recalled dietary information such as specific foods consumed, frequency, or portion sizes, thereby limiting our ability to obtain accurate risk estimates. However, the use of nutrient densities to describe nutrient intake partly corrects for potential over- or underreporting among participants (18). Although we considered potential confounding by glycemic load, overall diet quality (Alternative Healthy Eating Index), and intakes of saturated fat, carbohydrate, protein, fruit and vegetables, sugar-sweetened beverages, or fiber from grains, it is possible that some other unmeasured dietary factor associated with both processed meat intake and diabetes risk may have confounded our risk estimates. In our analyses, we excluded participants with unreasonably low or high estimated daily caloric intake; only $\sim$5% of the original cohort was excluded from analyses with the use of our established criteria. In sensitivity analyses, we assessed if using more conservative criteria would affect risk estimates by repeating all analyses with cutoffs used in other large epidemiologic studies (4, 26), whereby men with daily dietary intakes of <800 calories or >4200 calories and women with daily dietary intakes of <600 calories or >3200 calories were excluded. By using these thresholds, 21% of the cohort was excluded from analyses because of larger reported caloric intake. However, the magnitudes of the ORs for incident diabetes were unchanged. Thus, our OR estimates were stable regardless of the exclusion criteria used. Finally, our studied cohort comprised AIs from 13 communities in Arizona, North Dakota, South Dakota, and Oklahoma. The generalizability of our findings to other populations is unclear, although other disadvantaged groups also receive spam as part of the commodity foods program.

In conclusion, the results of this study suggest that processed meat intake, particularly spam consumption, is associated with a higher risk of diabetes. This study adds to the growing body of evidence identifying diet as an important determinant of incident diabetes and suggests a potential dietary target for interventions to prevent diabetes in AIs.

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The authors' responsibilities were as follows—AMF: was responsible for developing the research question of interest, performing the literature review and data analysis for the project, and writing the manuscript; BVH and DSS: were the senior investigators on the project and supervised all activities and aided in all aspects of the project, including development of the research question and writing the manuscript; GED and SAAB: participated in all analyses and in writing the manuscript; BM: was the biostatistician on the project, supervised the statistical methods, and reviewed all drafts of the manuscript; and MM, SE-A, and YZ: reviewed and edited all drafts of the manuscript and helped write the "Results" and "Discussion" sections of the manuscript. AMF had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. There are no conflicts of interest for any authors.

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