The Journal of Nutrition
Nutritional Epidemiology

Full-Fat Dairy Food Intake is Associated with a Lower Risk of Incident Diabetes Among American Indians with Low Total Dairy Food Intake

Kim Kummer,[1] Paul N Jensen,[2] Mario Kratz,[1,3] Rozenn N Lemaitre,[2] Barbara V Howard,[4,5] Shelley A Cole,[6] and Amanda M Fretts[1]

[1]Department of Epidemiology; [2]Department of Medicine, University of Washington, Seattle, WA; [3]Fred Hutchinson Cancer Research Center, Seattle, WA; [4]Medstar Health Research Institute, Hyattsville, MD; [5]Georgetown and Howard Universities Center for Translational Sciences, Washington, DC; and [6]Texas Biomedical Research Institute, San Antonio, TX

ABSTRACT

Background: Diet plays a key role in development of diabetes, and there has been recent interest in better understanding the association of dairy food intake with diabetes.

Objective: This study examined the associations of full-fat and low-fat dairy food intake with incident diabetes among American Indians—a population with a high burden of diabetes.

Methods: The study included participants from the Strong Heart Family Study (SHFS), a family-based study of cardiovascular disease in American Indians, free of diabetes at baseline (2001–2003) ($n = 1623$). Participants were 14–86-y-old at baseline and 60.8% were female. Dairy food intake was assessed using a Block food frequency questionnaire. Incident diabetes was defined using American Diabetes Association criteria. Parametric survival models with a Weibull distribution were used to evaluate the associations of full-fat and low-fat dairy food intake with incident diabetes. Serving sizes were defined as 250 mL for milk and 42.5 g for cheese.

Results: We identified 277 cases of diabetes during a mean follow-up of 11 y. Reported intake of dairy foods was low [median full-fat dairy food intake: 0.11 serving/1000 kcal; median low-fat dairy food intake: 0.03 serving/1000 kcal]. Participants who reported the highest full-fat dairy food intake had a lower risk of diabetes compared to those who reported the lowest full-fat food dairy intake [HR (95% CI): 0.79 (0.59, 1.06); P-trend = 0.03, comparing extreme tertiles, after adjustment for age, sex, site, physical activity, education, smoking, diet quality, and low-fat dairy food intake]. Low-fat dairy food intake was not associated with diabetes.

Conclusions: American Indians who participated in the SHFS reported low dairy food intake. Participants who reported higher full-fat dairy food intake had a lower risk of diabetes than participants who reported lower intake. These findings may be of interest to populations with low dairy food intake. *J Nutr* 2019;149:1238–1244.

Keywords: dairy food intake, high-fat dairy foods, low-fat dairy foods, diabetes, American Indians, diet

Introduction

In recent decades, there has been a dramatic increase in the prevalence of diabetes in the United States. This burden is particularly troubling among American Indians—whose prevalence of diabetes is 2.5 times higher than that of the general population (1). Obesity and poor diet are common among American Indians, and this may in part explain the high burden of diabetes in American Indian communities (2).

Diet plays a key role in the development of diabetes, and there has been recent interest in better understanding the association of dairy intake with diabetes. Although not conclusive, the mechanisms through which higher intake of dairy foods may improve glucose homeostasis include the high density of micronutrients including calcium, magnesium, and vitamin D in dairy, or direct physiological effects of specific amino acids or fatty acids in dairy (3–14). However, results of published studies that have examined associations of dairy food intake with incident diabetes are largely inconsistent (15–28), with studies suggesting that full-fat dairy food intake (but not low-fat dairy food intake) (15–18), low-fat dairy food intake (but not full-fat dairy food intake) (19–26), or neither full-fat nor low-fat dairy food (27, 28) intake are associated with a lower risk of diabetes.

To date, no studies have examined the association of dairy food intake with incident diabetes among American Indians. Because of the disproportionate burden of diabetes among American Indians, it is important to understand the relation of

Manuscript received November 5, 2018. Initial review completed December 10, 2018. Revision accepted March 11, 2019.
First published online May 9, 2019; doi: https://doi.org/10.1093/jn/nxz058.

dairy food intake with incident diabetes to help strengthen local nutritional dietary guidelines and inform diabetes prevention efforts.

The goal of this analysis was to assess the relation of full-fat and low-fat dairy food intake with incident diabetes among participants from the Strong Heart Family Study (SHFS).

Methods

Study setting

The SHFS is a family-based cohort study of risk factors for cardiovascular diseases in 12 American Indian communities in Arizona, North Dakota, South Dakota, and Oklahoma. The study included a baseline examination (2001–2003) and a follow-up examination (2007–2009). Each examination included a standardized personal interview, physical examination, medication review, and laboratory testing, as described previously (29). In total, 1122 men and 1658 women from 91 large families completed the baseline examination, of whom 91% also completed the follow-up examination. The SHFS protocol was approved by the institutional review boards from each Indian Health Service region and the 12 participating communities, and written informed consent was obtained from all participants at each examination. All procedures followed were in accordance with the Helsinki Declaration of 1975 as revised in 1983.

Subjects and methods

For this analysis, we excluded participants who had diabetes at baseline (n = 527) and those without follow-up (n = 245). Participants lost to follow-up were more likely to be male (61% compared with 39%) but were otherwise similar to participants who completed follow-up. In addition, we excluded individuals with a history of kidney failure (n = 14), myocardial infarction (n = 64), stroke (n = 22), heart failure (n = 12), or who were pregnant at baseline (n = 3) because these conditions may influence diet or diabetes risk. Participants with unreliable dietary information were also excluded, including those who did not complete the FFQ (n = 128), those who skipped >15 of the 119 questions on the FFQ (n = 31), and those who reported extreme caloric intakes [intakes of <600 kcal/d or >6000 kcal/d for women (n = 71) and <600 kcal/d or >8000 kcal/d for men (n = 40)]. The remaining 1623 persons comprised the analytic sample (**Supplemental Figure 1**).

Dietary assessment

An interviewer-administered 119-item Block FFQ was used to measure usual food intake during the previous year at baseline. The Block FFQ is a widely used food questionnaire, and its validity and reliability has been well-established (30, 31). In addition to food items on the standard Block FFQ, participants were asked about intake of foods commonly consumed in the participating American Indian communities, such as menudo, pozole, guysava, red or green chili, Indian taco, fry bread, corn tortilla, flour tortilla, and canned meat. Each participant was asked how often, on average, a particular food was consumed during the previous year. The quantity was assessed using measures of consumption frequency and portion size. This information was used to estimate mean daily energy and nutrient intakes for each study participant using the Block database (Block Dietary Systems).

For this analysis, we were primarily interested in full-fat dairy food intake and low-fat dairy food intake. Total intake of full-fat dairy foods was defined as the sum (serving/d) of whole milk, cheese, and cheese spreads. Total intake of low-fat dairy foods was defined as the sum (serving/d) of nonfat milk, 1% milk, 2% milk, and low-fat or reduced-fat cheese alternatives (<20% fat). Values for these variables were derived from the following questions on the Block FFQ: (1a) How often, on average, did you drink milk (any kind) during the past year? (responses: never, a few times per year, 1 time/mo, 2–3 times/mo, 1 time/wk, 2 times/wk, 3–4 times/wk, 5–6 times/wk, every day); (1b) How much milk, on average, did you usually drink? (responses: 1 glass, 2 glasses, 3 glasses, 4 glasses; a typical "glass" serving size was illustrated with a graphic); (1c) When you drink glasses of milk, what kind do you usually drink? (responses: whole milk, reduced-fat 2% milk, low-fat 1% milk, nonfat milk, rice milk, soy milk, I don't drink milk or soy milk); (2a) How often, on average, did you have milk on cereal during the past year? (this question was asked after ascertaining intake of hot and cold breakfast cereals; responses: never, a few times per year, 1 time/mo, 2–3 times/mo, 1 time/wk, 2 times/wk, 3–4 times/wk, 5–6 times/wk, every day); (2b) How many ounces of milk, on average, do you put on cereal? (responses: ≤3, 4–5, 6–7, ≥8; ounces illustrated with a graphic); (3a) How often, on average, did you eat cheese, sliced cheese, or cheese spread, including on sandwiches during the past year (responses: never, a few times per year, 1 time/mo, 2–3 times/mo, 1 time/wk, 2 times/wk, 3–4 times/wk, 5–6 times/wk, every day); (3b) How many slices of cheese? (Responses: 1, 2, 3, 4); (3c) When you eat cheese, is it: usually low-fat, sometimes low-fat, hardly ever low-fat, don't know/don't eat. We a priori excluded yogurt from the categorization of full-fat and low-fat dairy foods to avoid bias in dairy categorization because the Block FFQ collected yogurt intake as part of a question on "intake of yogurt, frozen yogurt, and nondairy desserts" and did not differentiate between full-fat and low-fat options.

Full-fat dairy food intake and low-fat dairy food intake were expressed using nutrient densities (serving/1000 kcal) to adjust for over-reporting and under-reporting of intake. The standard daily serving sizes used were consistent with USDA serving sizes: 250 mL (8 ozs) for whole milk, 2% milk, 1% milk, or nonfat milk, and 42.5 g (1.5 ozs) for cheese.

Diabetes assessment

Blood samples were collected after a 12-h overnight fast and were stored at −70°C. Incident type 2 diabetes was defined based on the American Diabetes Association criteria as fasting glucose concentration ≥126 mg/dL, or use of insulin or oral antidiabetic medications at the baseline or follow-up examinations (32). Subsequent to the follow-up examination (2007–2009), diabetes surveillance was performed using a single phone interview and medical record review; all phone interviews and medical record reviews occurred between 2013 and 2017, and 1373 participants (85%) completed the interviews/medical record review. During this time, diabetes was identified by self-report and confirmed by documentation in medical records. Because type 1 diabetes is rare in American Indian populations and all SHFS participants were aged ≥18 y at baseline, all new occurrences of diabetes were assumed to be type 2.

Other covariates

Information on education, and smoking and alcohol use were obtained by trained interviewers using standardized questionnaires. Anthropometric measures were obtained with the participant wearing lightweight clothing and no shoes. BMI was calculated as body weight divided by height-squared (kg/m^2). Accusplit AE120 pedometers were used to measure total physical activity. The pedometers have been shown to be both reliable and valid in previous laboratory studies (33–40).

Statistical analyses

Parametric survival models with a Weibull distribution were used to examine the associations of full-fat and low-fat dairy food intake with

The Strong Heart Family Study (SHFS) is supported by the National Heart, Lung, and Blood Institute cooperative agreement grants U01 HL65520, U01 HL41642, U01 HL41652, U01 HL41654, U01 HL65521, and R01HL109301. AMF is also supported by 5KL2TR000421.

Author disclosures: KK, PNJ, RNL, BVH, SAC, and AMF, no conflicts of interest. MK has received reimbursements for travel, honoraria, and a research grant from dairy-related organizations.

Supplemental Tables 1–6 and Supplemental Figure 1 are available from the "Supplementary data" link in the online posting of the article and from the same link in the online table of contents at https://academic.oup.com/jn/.

Address correspondence to AMF (e-mail: amfretts@u.washington.edu).

Abbreviations used: AHEI, alternative healthy eating index; RCT, randomized controlled trial; SHFS, Strong Heart Family Study.

incident diabetes. These models were selected for the analysis to account for interval-censored incident diabetes. Participants were followed until the earliest of development of diabetes, death, or loss to follow-up—at which time they stopped contributing time-at-risk to analyses. The SHFS comprised extended families, so robust standard error estimates that account for clustering of risk factors among family members were used. Intakes of low-fat and full-fat dairy foods were assessed categorically using indicator (i.e., dummy) tertiles with participants in the lowest tertile of intake comprising the reference group. Finer categorization was not possible because of the low reported intake of dairy foods in the population. For each analysis, tests for linear trend were assessed by running analyses that modeled low-fat and full-fat dairy food intake as continuous exposures, rather than as dummy variables. All statistical analyses were conducted using R version 3.4.3 (R Core Team).

Covariates were selected a priori based on their potential associations with dairy food intake and incident diabetes. Three models were fit to examine the associations of full-fat and low-fat dairy food intake with incident diabetes. A crude model included adjustments for age, sex, study site, and total energy intake. A second model (primary model) additionally adjusted for a priori confounders, including ambulatory physical activity (steps/d), education (y), smoking status (never, former, current), reported intake of full-fat dairy foods (for analyses of low-fat dairy foods and diabetes), reported intake of low-fat dairy foods (for analyses of full-fat dairy foods and diabetes), and the alternative healthy eating index (AHEI). The AHEI is a diet quality index based on foods and nutrients associated with risk of chronic diseases. Details of the AHEI have been reported in detail previously (41). The AHEI comprises 11 foods and nutrients: vegetables, fruit, wholegrains, nuts and legumes, long chain ω-3 fatty acids, PUFA, alcohol, sugar-sweetened beverages and fruit juice, red and processed meat, *trans* fat, and sodium. More favorable foods score higher, and thus contribute to an overall higher score, indicating higher quality of diet (poorest diets have a score of 0, whereas most optimal diets have a score of 110). As BMI may confound or mediate the relation of dairy food intake and incident diabetes, we additionally adjusted for BMI in a third model (exploratory model).

For all analyses, multiple imputations were used to account for occasional missing values (<1% for all covariates) using the Fully Conditional Expectation method implemented by the MICE package in R with the predictive mean matching method (42). Sex, age, site, alcohol consumption, and other diet factors were used to predict imputed values across 20 data sets.

As the relation of dairy food intake and diabetes may differ by sex, obesity, or age, we examined potential effect modification of these factors with full-fat dairy food intake and low-fat dairy food intake on incident diabetes in sensitivity analyses. To evaluate effect modification, a multiplicative term was created individually for sex, BMI, and age with dairy food intake on incident diabetes. Wald tests were used to test the statistical significance of the interaction terms. In exploratory analyses, we examined associations of the most commonly consumed dairy foods (i.e., whole milk, low-fat or nonfat, and full-fat cheese) with incident diabetes. As it is possible that diet and/or other risk factors for diabetes may have changed throughout follow-up, we performed sensitivity analyses truncating follow-up post the 2007–2009 examination. We also performed sensitivity analyses that included reported intake of cream, ice cream, and butter in the classification of full-fat dairy food intake.

Results

The median age at baseline was 36 y (range 14–86 y) and 60.8% of participants were female. Reported intake of full-fat and low-fat dairy foods was low [median daily full-fat intake 0.11 serving/1000 kcal (range 0–2.5 serving/1000 kcal), median daily low-fat dairy intake 0.03 serving/1000 kcal (range 0–4.5 serving/1000 kcal)]. Nine percent (n = 148) of participants reported never consuming any full-fat dairy foods and 40% (n = 646) of participants reported never consuming any low-fat dairy foods.

Baseline characteristics of study participants according to tertile of full-fat and low-fat dairy food intake are shown in **Table 1**. Participants who reported higher intake of full-fat dairy foods were younger, more likely to be male, and reported higher intake of saturated fat and total calories, and lower intake of cereal fiber and nuts, peanut butter, and soy than participants who reported lower intakes of full-fat dairy foods. Participants who reported higher intake of low-fat dairy foods were more likely to be female, more physically active, and had a slightly higher intake of fruits and vegetables and cereal fiber, and lower intake of processed meats and sugar-sweetened beverages compared to participants who reported lower intakes of low-fat dairy foods.

There were 277 participants who developed diabetes during a mean follow-up of 11 y. Participants who reported the highest intake of full-fat dairy foods had a lower risk of developing diabetes when compared to participants who reported the lowest intake of full-fat dairy foods. Compared to the lowest tertile of full-fat dairy food intake, HR (95% CI) for the upper 2 tertiles of intake were 0.88 (95% CI: 0.63, 1.23) and 0.79 (95% CI: 0.59, 1.06), respectively, after adjustment for potential confounders (P-trend = 0.03) (**Table 2**). Additional adjustment for BMI attenuated this association. No association of reported low-fat dairy food intake and incident diabetes was observed (Table 2). There were no significant interactions between dietary factors and age, sex, or BMI on risk of diabetes, although power to detect interaction was limited. Results of analyses stratified by age, sex, and BMI categories are shown in **Supplemental Tables 1–3**. Exploratory analyses of individual foods (i.e., intake of full-fat milk, nonfat or low-fat milk, and full-fat cheese) are reported in **Supplemental Table 4**. Sensitivity analyses that truncated post-follow-up (2007–2009) exam produced 40% fewer cases of diabetes because of shorter follow-up; although the magnitude of the risk estimates were not materially changed, results were no longer statistically significant (**Supplemental Table 5**). In addition, the median (IQR) reported intakes of cream, ice cream, and butter were 0.0 (0.0, 0.0), 0.04 (0.01, 0.08), and 0.05 (0.0, 0.19) servings/d, respectively, and sensitivity analyses that included these foods in the classification of full-fat dairy foods did not meaningfully change results (**Supplemental Table 6**).

Discussion

Results from this large prospective study in American Indians with low reported dairy food intake suggest that full-fat dairy food intake—but not low-fat dairy food intake—is associated with a lower risk of developing diabetes. In addition, these findings highlight the exceedingly low intake of dairy foods (both full-fat and low-fat) among American Indians from the SHFS.

Results of previous studies that assessed associations of dairy food intake with incident diabetes are conflicting. A handful of previous studies have shown that higher intake of full-fat (but not low-fat) dairy foods is associated with a lower risk of diabetes, and the magnitude of reported risk estimates is similar to that observed in the SHFS (15–18). However, some other studies, including a large meta-analysis, have reported inverse associations of low-fat dairy foods (but not full-fat dairy foods) with diabetes (19–26). Differences in study results may be caused by lack of homogeneity between dietary ascertainment methods (e.g., different types of FFQ, diet recall) or in the definitions of full-fat compared with low-fat dairy foods across

TABLE 1 Baseline characteristics of Strong Heart Family Study participants according to tertiles of full-fat and low-fat dairy food intake[1]

Characteristic	Full-fat dairy food intake (serving/1000 kcal)[2]			Low-fat dairy food intake (serving/1000 kcal)[3]		
	<0.05	0.05 to <0.18	≥0.18	0	0 to <0.13	≥0.13
	$n = 541$	$n = 541$	$n = 541$	$n = 646$	$n = 426$	$n = 551$
Median intake (IQR) of full-fat dairy (serving/1000 kcal)	0.02 (0.00, 0.03)	0.11 (0.08, 0.14)	0.34 (0.25, 0.51)	0.22 (0.09, 0.42)	0.07 (0.02, 0.14)	0.07 (0.02, 0.15)
Median intake (IQR) of low-fat dairy (serving/1000 kcal)	0.09 (0.010, 0.35)	0.05 (0, 0.28)	0.00 (0.00, 0.05)	0.00 (0.00, 0.00)	0.04 (0.02, 0.08)	0.40 (0.24, 0.70)
Age, y	38.5 ± 16.2	36.1 ± 14.7	35.6 ± 14.6	36.4 ± 14.7	37.4 ± 14.5	36.6 ± 16.4
Female, %	63.6	61.2	57.5	57.7	65.6	60.4
BMI, kg/m^2	30.8 ± 7.4	30.5 ± 7.3	30.1 ± 7.0	29.7 ± 6.6	31.6 ± 7.6	30.6 ± 7.6
Fasting glucose, mg/dL	93.6 ± 10.5	93.5 ± 10.0	93.7 ± 10.1	93.4 ± 10.3	94.0 ± 10.0	93.5 ± 10.2
Education, y	12.4 ± 2.4	12.4 ± 2.2	12.1 ± 2.1	12.1 ± 1.9	12.5 ± 2.2	12.3 ± 2.6
Pedometer, step/d	6237 ± 4168	6396 ± 4102	6517 ± 3728	6175 ± 3621	6006 ± 3686	6937 ± 4581
Smoking, %						
Never	42.7	41.3	40.5	39.2	41.5	44.3
Ever	21.3	20	21.1	17.3	20.9	24.8
Current	36.0	38.7	38.4	43.5	37.6	30.9
Total energy, kcal	2337 ± 1301	2522 ± 1372	2573 ± 1331	2489 ± 1361	2416 ± 1297	2513 ± 1344
Whole milk, serving/1000 kcal	0.00 ± 0.01	0.02 ± 0.03	0.25 ± 0.34	0.21 ± 0.31	0.01 ± 0.07	0.00 ± 0.03
Non/low-fat milk, serving/1000 kcal	0.25 ± 0.38	0.21 ± 0.37	0.10 ± 0.26	0.0 ± 0.0	0.05 ± 0.04	0.52 ± 0.44
Cheese or cheese spreads, serving/1000 kcal	0.02 ± 0.02	0.09 ± 0.04	0.20 ± 0.15	0.11 ± 0.11	0.10 ± 0.11	0.11 ± 0.13
Fruit and vegetables, serving/1000 kcal	1.7 ± 1.0	1.5 ± 0.8	1.5 ± 0.8	1.4 ± 0.8	1.6 ± 0.9	1.7 ± 0.9
Processed meat, g/1000 kcal	13.4 ± 10.4	14.5 ± 10.3	14.2 ± 9.6	15.0 ± 10.5	13.6 ± 10.0	13.2 ± 9.5
Unprocessed meat, g/1000 kcal	24.0 ± 18.1	23.0 ± 14.6	23.7 ± 18.3	23.8 ± 17.1	24.8 ± 17.6	22.3 ± 16.5
Sugar-sweetened beverages, g/1000 kcal	224 ± 228	229 ± 218	219 ± 197	251 ± 235	241 ± 224	177 ± 169
Cereal fiber, g/1000 kcal	8.8 ± 12.6	7.8 ± 10.2	7.5 ± 9.1	6.8 ± 9.3	7.2 ± 11.1	10.2 ± 11.7
Peanut butter, nuts, and soy, serving/1000 kcal	0.33 ± 0.38	0.29 ± 0.29	0.27 ± 0.31	0.28 ± 0.34	0.32 ± 0.36	0.30 ± 0.29
Polyunsaturated fat, % kcal	8.5 ± 2.5	8.6 ± 2.2	8.2 ± 2.4	8.4 ± 2.5	8.8 ± 2.5	8.2 ± 2.0
Saturated fat, % kcal	10.8 ± 2.2	11.2 ± 2.1	12.4 ± 2.9	11.7 ± 3.0	11.1 ± 2.1	11.6 ± 2.1
Trans fat, % kcal	1.6 ± 0.63	1.6 ± 0.52	1.6 ± 0.59	1.6 ± 0.63	1.6 ± 0.64	1.6 ± 0.45
Alternate Healthy Eating Index, score	44.5 ± 9.6	44.1 ± 8.5	43.5 ± 8.7	43.1 ± 8.5	44.1 ± 8.7	45.1 ± 9.6

[1]Values are mean ± SD, median (IQR), or %.
[2]Full-fat dairy food group consisted of whole milk, and cheese and cheese spreads with 1 serving = 250 mL (8 ozs) of milk or 42.5 g (1.5 ozs) of cheese or cheese spread.
[3]Low-fat dairy food group consisted of 2% milk, 1% milk, nonfat milk, and low-fat cheese and cheese spreads with 1 serving = 250 mL (8 ozs) of milk or 42.5 g (1.5 ozs) of cheese or cheese spread.

studies. On the other hand, studies that assessed the associations of biomarkers of full-fat dairy food intake, such as circulating concentrations of pentadecanoic acid (15:0), heptadecanoic acid (17:0), and *trans*-palmitoleic acid (t-16:1n-7), consistently reported inverse associations with incident diabetes (6, 8, 43).

In the present analysis, across the 3 tertiles, median daily intakes of full-fat and low-fat dairy foods were 0.02–0.33 serving/1000 kcal and 0–0.40 serving/1000 kcal, respectively. In other large cohort studies, such as the Nurses' Health Study and the Health Professionals Follow-Up Study, the range of daily intake of full-fat dairy and low-fat dairy foods was much higher (i.e., ∼0.5–1.5 serving/1000 kcal and 0.5–2.0 serving/1000 kcal, respectively) (15, 23, 27). However, the demographic characteristics of those studies are very different from the SHFS. For instance, the Nurses' Health Study largely comprised participants with high levels of education who reside in urban or suburban communities. Nevertheless, SHFS participants do not meet current USDA dietary guidelines that recommend dairy consumption as part of a healthy diet.

The purpose of this analysis was to assess potential differential associations of reported intake of full-fat dairy foods and low-fat dairy foods with incident diabetes in a head-to-head and meaningful way. Results of previous studies that have examined associations of full-fat compared with low-fat dairy food with incident diabetes have been inconsistent, likely because of (at least in part) the categorization of full-fat and low-fat dairy foods. In particular, several studies include a wide spectrum of full-fat and low-fat dairy foods in the categorization of full-fat and low-fat food intake—and essentially compare individuals with poor overall diet quality (e.g., those who consume ice cream and heavy cream regularly) to individuals who drink skim milk and consume low-fat cheese regularly. As poor diet quality may reflect other health behaviors (e.g., low physical activity, much sedentary behavior, obesity, smoking) (44), it is not surprising that some of these studies suggest that low-fat dairy food intake (but not full-fat dairy food intake) is associated with a lower risk of diabetes (19–26). To build upon previous work on this topic, we a priori decided to only include foods for which there were both full-fat and low-fat options;

TABLE 2 Associations of full-fat or low-fat dairy food intake with incident diabetes among participants in the Strong Heart Family Study[1]

	Tertile 1	Tertile 2	Tertile 3	*P*-trend
Full-fat dairy food intake, serving/1000 kcal[2]	<0.05	0.05 to <0.18	≥0.18	
Median intake (IQR)	0.02 (0.00, 0.03)	0.11 (0.08, 0.14)	0.34 (0.25, 0.51)	
No. of cases	103	93	81	
Total no. at risk	541	541	541	
Median follow-up time, y	12.6	12.6	12.5	
Minimally adjusted[3]	1.0	0.88 (0.63, 1.24)	0.79 (0.61, 1.03)	0.09
Multivariate[4]	1.0	0.88 (0.63, 1.23)	0.79 (0.59, 1.06)	0.03
BMI[5]	1.0	0.90 (0.64, 1.27)	0.83 (0.60, 1.15)	0.08
Low-fat dairy food intake, serving/1000 kcal[6]	0	0 to <0.13	≥0.13	
Median intake (IQR)	0 (0, 0)	0.04 (0.02, 0.08)	0.40 (0.24, 0.70)	
No. of cases	105	78	94	
Total no. at risk	646	436	541	
Median follow-up time, y	12.7	12.5	12.6	
Minimally adjusted[3]	1.0	1.06 (0.79, 1.42)	1.07 (0.82, 1.40)	0.61
Multivariate[7]	1.0	0.98 (0.70, 1.36)	1.02 (0.74, 1.42)	0.88
BMI[5]	1.0	0.93 (0.70, 1.25)	0.91 (0.67, 1.23)	0.52

[1]Values are servings/1000 kcal, median (IQR), n, y, or HR (95% CI).
[2]Full-fat dairy food group consisted of whole milk, and cheese and cheese spreads with 1 serving = 250 mL (8 ozs) of milk or 42.5 g (1.5 ozs) of cheese or cheese spread.
[3]Adjusted for age, sex, site, and total caloric intake.
[4]Additionally adjusted for education, physical activity, smoking status, diet quality (alternative healthy eating index), low-fat dairy food intake.
[5]Additionally adjusted for BMI.
[6]Low-fat dairy food group consisted of 2% milk, 1% milk, nonfat milk, and low-fat cheese and cheese spreads with 1 serving = 250 mL (8 ozs) of milk or 42.5 g (1.5 ozs) of cheese or cheese spread.
[7]Additionally adjusted for education, physical activity, smoking status, diet quality (alternative healthy eating index), full-fat dairy food intake.

cream, ice cream, or yogurt/nondairy desserts were not included in the classification of full-fat or low-fat dairy foods because of a lack of commonly consumed (dairy-based) low-fat alternatives included on the FFQ. In addition, as yogurt and frozen yogurt were grouped with nondairy desserts as a single line item on the Block FFQ, including this item in the classification of full-fat or low-fat dairy would introduce misclassification of dairy intake (i.e., include nondairy foods in reported dairy intake). Although we ran analyses that included cream, ice cream, and butter in the classification of full-fat dairy foods to increase comparability with previous work, it is not surprising that our results remained unchanged because reported intake of these foods was low.

In addition to examining the associations of full-fat dairy food intake and low-fat dairy food intake with incident diabetes, some large studies examined intake of individual dairy foods with risk of diabetes. Similar to studies that examined total intake of full-fat and low-fat dairy foods with incident diabetes, results of these studies are inconsistent. In 1 study, higher intake of cream, cheese, and high-fat fermented milk were each associated with a lower risk of diabetes (compared to lower intake), whereas intake of low-fat milk (both fermented and nonfermented) was not associated with diabetes risk (16). On the other hand, findings from the Health Professionals Follow-Up Study reported that only low-fat milk is inversely associated with diabetes risk, whereas intake of yogurt, cream, and cheese are not associated with diabetes risk (23). Results of meta-analyses are similarly conflicting (19, 22), likely because of underlying differences in diet or other health behaviors across populations studied, or differences in diet ascertainment methods. Unfortunately, intakes of dairy foods in the SHFS were too low to have adequate power to examine associations of individual dairy foods with incident diabetes (Supplemental Table 4).

A few randomized controlled trials (RCTs) have assessed the impact of dairy food intake with glucose tolerance and/or insulin sensitivity (all in individuals without diabetes), and results do not conclusively support a beneficial effect (45–53) However, most published studies focused on intake of low-fat dairy foods alone (47, 49, 51, 53–56); only 1 study examined the effect of full-fat compared with low-fat dairy food intake (i.e., cheese) on glucose homeostasis (45). Results of these RCTs are difficult to interpret because most were short (study duration of 4–12 wk) (45–47, 49, 51–53, 55, 56) and not designed to specifically examine the effects of dairy foods on glucose and/or insulin markers (45, 47–49, 54, 56). Further, most of these RCTs comprised healthy populations with normal glucose tolerance and/or insulin sensitivity at baseline (46, 47, 49, 51–54, 56)—in whom clinically meaningful improvements in glucose or insulin were not possible. Future RCTs that examine the effects of full-fat compared with low-fat dairy food intake on markers of glucose homeostasis in populations at high risk for diabetes are needed.

The mechanism by which intake of dairy foods may influence risk of diabetes is complex. Whey protein, a protein found in milk, stimulates generation of amino acids and peptides in the gastrointestinal tract during digestion that have been shown to signal the release of gut hormones (e.g., glucagon-like peptide 1) that affect energy homeostasis and insulin secretion in β cells (4, 5). Dairy foods are also high in micronutrients such as calcium, magnesium, and vitamin D that are inversely associated with the metabolic syndrome and diabetes (3, 10–12) and improvements in β cell function and insulin-sensitivity (13). Finally, some evidence suggests that unique fatty acids in dairy, including *trans*-palmitoleic acid (t-16:1n-7), SCFA such as butyric acid, or branched-chain fatty acids such as phytanic acid, may improve insulin sensitivity by reducing hepatic TG content (6–9, 14, 57).

In many populations, intake of dairy foods is a major contributor to total daily saturated fat intake. In the SHFS, the Pearson correlation of high-fat dairy food intake (servings/d) and saturated fat was moderate (r = 0.30). As intake of dairy foods in SHFS is low, daily saturated fat intake may also be influenced by other foods commonly consumed in the population, such as processed meats and fried foods.

Associations of full-fat dairy foods and incident diabetes were no longer statistically significant after additional adjustment for BMI. However, BMI may be in the causal pathway of dairy food intake and diabetes (i.e., diet may impact BMI—which influences diabetes risk), and a model that adjusts for BMI may be conservative (58).

This study has several strengths, including the availability of a large, family-based sample, prospective design, use of validated dietary instruments, and standardized indices for assessing dairy intake. In addition, our classification of full-fat compared with low-fat dairy foods is clear and interpretable; many previous studies that have assessed associations of dairy intake with diabetes risk include not only milk, cheese, and yogurt in the full-fat dairy category, but also ice cream, heavy cream, and butter—foods for which there are no commonly used low-fat (dairy-based) alternatives—rendering it challenging to directly compare full-fat with low-fat dairy intake and incident diabetes. This study also has limitations. The limitations of the FFQ meant that we were unable to include yogurt in our classification of dairy food intake. However, reported intake of yogurt, frozen yogurt, and nondairy desserts was very low and unlikely to impact results [median reported intake = 0 g/1000 kcal; 60% of participants (n = 965) reported no consumption; 7% of participants (n = 113) reported consuming at least 1 serving (8 oz)/wk of which 1 participant reported consuming at least 1 serving/d]. We only had 1 measure of diet (at baseline); if participants did not accurately recall diet during the previous year, or if participants altered intake of full-fat or low-fat dairy foods over time, observed associations may be an underestimate of true associations because of nondifferential misclassification. Information on lactose-intolerance was not collected as part of the SHFS, and we were unable to account for dairy sensitivities in analyses. Although the SHFS collected detailed data on many factors that may influence diet and/or diabetes risk, residual confounding by unmeasured or poorly measured factors is possible.

In conclusion, American Indians who participated in the SHFS reported low dairy food intake—well below USDA dietary recommendations. Despite low reported intake, higher reported intake of full-fat dairy foods (but not low-fat dairy foods) was associated with a lower risk of incident diabetes. These findings may be of interest to other populations with low dairy food intake.

Acknowledgments

The authors' responsibilities were as follows—AMF and MK: designed the research; KK and PNJ: analyzed data; BVH and SAC: provided essential material; KK, PNJ, MK, RNL, BVH, SAC, and AMF: wrote the paper; AMF: primary responsibility for the final content; and all authors: read and approved the final paper.

References

1. Acton KJ, Burrows NR, Moore K, Querec L, Geiss LS, Engelgau MM. Trends in diabetes prevalence among American Indian and Alaska native children, adolescents, and young adults. Am J Public Health 2002;92(9):1485–90.
2. Fretts AM, Howard BV, McKnight B, Duncan GE, Beresford SA, Mete M, Zhang Y, Siscovick DS. Life's Simple 7 and incidence of diabetes among American Indians: the Strong Heart Family Study. Diabetes Care 2014;37(8):2240–5.
3. Rice BH, Cifelli CJ, Pikosky MA, Miller GD. Dairy components and risk factors for cardiometabolic syndrome: recent evidence and opportunities for future research. Adv Nutr 2011;2(5):396–407.
4. Jakubowicz D, Froy O. Biochemical and metabolic mechanisms by which dietary whey protein may combat obesity and type 2 diabetes. J Nutr Biochem 2013;24(1):1–5.
5. Belobrajdic DP, McIntosh GH, Owens JA. A high-whey-protein diet reduces body weight gain and alters insulin sensitivity relative to red meat in Wistar rats. J Nutr 2004;134(6):1454–8.
6. Mozaffarian D, Cao H, King IB, Lemaitre RN, Song X, Siscovick DS, Hotamisligil GS. Trans-palmitoleic acid, metabolic risk factors, and new-onset diabetes in U.S. adults: a cohort study. Ann Intern Med 2010;153(12):790–9.
7. Mozaffarian D, de Oliveira Otto MC, Lemaitre RN, Fretts AM, Hotamisligil G, Tsai MY, Siscovick DS, Nettleton JA. trans-Palmitoleic acid, other dairy fat biomarkers, and incident diabetes: the Multi-Ethnic Study of Atherosclerosis (MESA). Am J Clin Nutr 2013;97(4): 854–61.
8. Yakoob MY, Shi P, Willett WC, Rexrode KM, Campos H, Orav EJ, Hu FB, Mozaffarian D. Circulating biomarkers of dairy fat and risk of incident diabetes mellitus among men and women in the United States in two large prospective cohorts. Circulation 2016;133(17):1645–54.
9. Imamura F, Fretts A, Marklund M, Ardisson Korat AV, Yang WS, Lankinen M, Qureshi W, Helmer C, Chen TA, Wong K, et al. Fatty acid biomarkers of dairy fat consumption and incidence of type 2 diabetes: a pooled analysis of prospective cohort studies. PLoS Med 2018;15(10):e1002670.
10. Dong JY, Xun P, He K, Qin LQ. Magnesium intake and risk of type 2 diabetes: meta-analysis of prospective cohort studies. Diabetes Care 2011;34(9):2116–22.
11. Pittas AG, Lau J, Hu FB, Dawson-Hughes B. The role of vitamin D and calcium in type 2 diabetes. A systematic review and meta-analysis. J Clin Endocrinol Metab 2007;92(6):2017–29.
12. Mitri J, Muraru MD, Pittas AG. Vitamin D and type 2 diabetes: a systematic review. Eur J Clin Nutr 2011;65(9):1005–15.
13. Belin RJ, He K. Magnesium physiology and pathogenic mechanisms that contribute to the development of the metabolic syndrome. Magnes Res 2007;20(2):107–29.
14. Kratz M, Baars T, Guyenet S. The relationship between high-fat dairy consumption and obesity, cardiovascular, and metabolic disease. Eur J Nutr 2013;52(1):1–24.
15. Malik VS, Sun Q, van Dam RM, Rimm EB, Willett WC, Rosner B, Hu FB. Adolescent dairy product consumption and risk of type 2 diabetes in middle-aged women. Am J Clin Nutr 2011;94(3):854–61.
16. Ericson U, Hellstrand S, Brunkwall L, Schulz CA, Sonestedt E, Wallstrom P, Gullberg B, Wirfalt E, Orho-Melander M. Food sources of fat may clarify the inconsistent role of dietary fat intake for incidence of type 2 diabetes. Am J Clin Nutr 2015;101(5):1065–80.
17. Drehmer M, Pereira MA, Schmidt MI, Alvim S, Lotufo PA, Luft VC, Duncan BB. Total and full-fat, but not low-fat, dairy product intakes are inversely associated with metabolic syndrome in adults. J Nutr 2016;146(1):81–9.
18. Hruby A, Ma J, Rogers G, Meigs JB, Jacques PF. Associations of dairy intake with incident prediabetes or diabetes in middle-aged adults vary by both dairy type and glycemic status. J Nutr 2017;147(9):1764–75.
19. Aune D, Norat T, Romundstad P, Vatten LJ. Dairy products and the risk of type 2 diabetes: a systematic review and dose-response meta-analysis of cohort studies. Am J Clin Nutr 2013;98(4):1066–83.
20. Gao D, Ning N, Wang C, Wang Y, Li Q, Meng Z, Liu Y, Li Q. Dairy products consumption and risk of type 2 diabetes: systematic review and dose-response meta-analysis. PLoS One 2013;8(9):e73965.
21. Tong X, Dong JY, Wu ZW, Li W, Qin LQ. Dairy consumption and risk of type 2 diabetes mellitus: a meta-analysis of cohort studies. Eur J Clin Nutr 2011;65(9):1027–31.
22. Gijsbers L, Ding EL, Malik VS, de Goede J, Geleijnse JM, Soedamah-Muthu SS. Consumption of dairy foods and diabetes incidence: a dose-response meta-analysis of observational studies. Am J Clin Nutr 2016;103(4):1111–24.

23. Choi HK, Willett WC, Stampfer MJ, Rimm E, Hu FB. Dairy consumption and risk of type 2 diabetes mellitus in men: a prospective study. Arch Intern Med 2005;165(9):997–1003.
24. Liu S, Choi HK, Ford E, Song Y, Klevak A, Buring JE, Manson JE. A prospective study of dairy intake and the risk of type 2 diabetes in women. Diabetes Care 2006;29(7):1579–84.
25. Margolis KL, Wei F, de Boer IH, Howard BV, Liu S, Manson JE, Mossavar-Rahmani Y, Phillips LS, Shikany JM, Tinker LF. A diet high in low-fat dairy products lowers diabetes risk in postmenopausal women. J Nutr 2011;141(11):1969–74.
26. van Dam RM, Hu FB, Rosenberg L, Krishnan S, Palmer JR. Dietary calcium and magnesium, major food sources, and risk of type 2 diabetes in U.S. black women. Diabetes Care 2006;29(10):2238–43.
27. Chen M, Sun Q, Giovannucci E, Mozaffarian D, Manson JE, Willett WC, Hu FB. Dairy consumption and risk of type 2 diabetes: 3 cohorts of US adults and an updated meta-analysis. BMC Med 2014;12:215.
28. O'Connor LM, Lentjes MA, Luben RN, Khaw KT, Wareham NJ, Forouhi NG. Dietary dairy product intake and incident type 2 diabetes: a prospective study using dietary data from a 7-day food diary. Diabetologia 2014;57(5):909–17.
29. North KE, Howard BV, Welty TK, Best LG, Lee ET, Yeh JL, Fabsitz RR, Roman MJ, MacCluer JW. Genetic and environmental contributions to cardiovascular disease risk in American Indians: the Strong Heart Family Study. Am J Epidemiol 2003;157(4):303–14.
30. Block G, Thompson FE, Hartman AM, Larkin FA, Guire KE. Comparison of two dietary questionnaires validated against multiple dietary records collected during a 1-year period. J Am Diet Assoc 1992;92(6):686–93.
31. Subar AF, Thompson FE, Kipnis V, Midthune D, Hurwitz P, McNutt S, McIntosh A, Rosenfeld S. Comparative validation of the Block, Willett, and National Cancer Institute food frequency questionnaires: the Eating at America's Table Study. Am J Epidemiol 2001;154(12):1089–99.
32. American Diabetes Association. Standards of medical care in diabetes–2013. Diabetes Care 2013;36(Suppl 1):S11–66. doi: 10.2337/dc13-S011.
33. Schneider P, Crouter S, Lukajic O, Bassett D. Accuracy and reliability of 10 pedometers for measuring steps over a 400-m walk. Med Sci Sports Exerc 2003;35(10):1779–84.
34. Bassett D, Ainsworth B, Leggett S, Mathien C, Main J, Hunter D, Duncan G. Accuracy of five electronic pedometers for measuring distance walked. Med Sci Sports Exerc 1996;28(8):1071–7.
35. Tudor-Locke C, Ainsworth B, Thompson R, Matthews C. Comparison of pedometer and accelerometer measures of free-living physical activity. Med Sci Sports Exerc 2002;34(12):2045–51.
36. Le Masurier G, Tudor-Locke C. Comparison of pedometer and accelerometer under controlled conditions. Med Sci Sports Exerc 2003;35(3):867–71.
37. Le Masurier G, Lee S, Tudor-Locke C. Motion sensor accuracy under controlled and free-living conditions. Med Sci Sports Exerc 2004;36(5):905–10.
38. Schneider P, Crouter S, Bassett D. Pedometer measures of free-living physical activity: comparison of 13 models. Med Sci Sports Exerc 2004;36(2):331–5.
39. Crouter S, Schneider P, Karabulut M, Bassett D. Validity of 10 electronic pedometers for measuring steps, distance, and energy cost. Med Sci Sports Exerc 2003;35(8):1455–60.
40. Melanson E, Knoll J, Bell M, Donahoo W, Hill J, Nysse L, Lanningham-Foster L, Peters J, Levine J. Commercially available pedometers: considerations for accurate step counting. Prev Med 2004;39:361–8.
41. Chiuve SE, Fung TT, Rimm EB, Hu FB, McCullough ML, Wang M, Stampfer MJ, Willett WC. Alternative dietary indices both strongly predict risk of chronic disease. J Nutr 2012;142(6):1009–18.
42. Van Buuren S, Groothuis-Oudshoorn K. MICE: Multivariate Imputation by Chained Equations in R. J Stat Softw 2011;45 (3).
43. Santaren ID, Watkins SM, Liese AD, Wagenknecht LE, Rewers MJ, Haffner SM, Lorenzo C, Hanley AJ. Serum pentadecanoic acid (15:0), a short-term marker of dairy food intake, is inversely associated with incident type 2 diabetes and its underlying disorders, Am J Clin Nutr 2014;100(6):1532–40.
44. Meyer AM, Evenson KR, Couper DJ, Stevens J, Pereria MA, Heiss G. Television, physical activity, diet, and body weight status: the ARIC cohort. Int J Behav Nutr Phys Act 2008;5:68.
45. Raziani F, Tholstrup T, Kristensen MD, Svanegaard ML, Ritz C, Astrup A, Raben A. High intake of regular-fat cheese compared with reduced-fat cheese does not affect LDL cholesterol or risk markers of the metabolic syndrome: a randomized controlled trial. Am J Clin Nutr 2016;104(4):973–81.
46. Benatar JR, Jones E, White H, Stewart RA. A randomized trial evaluating the effects of change in dairy food consumption on cardio-metabolic risk factors. Eur J Prev Cardiol 2014;21(11):1376–86.
47. Dugan CE, Barona J, Fernandez ML. Increased dairy consumption differentially improves metabolic syndrome markers in male and female adults. Metab Syndr Relat Disord 2014;12(1):62–9.
48. Tanaka S, Uenishi K, Ishida H, Takami Y, Hosoi T, Kadowaki T, Orimo H, Ohashi Y. A randomized intervention trial of 24-wk dairy consumption on waist circumference, blood pressure, and fasting blood sugar and lipids in Japanese men with metabolic syndrome. J Nutr Sci Vitaminol 2014;60(5):305–12.
49. van Meijl LE, Mensink RP. Low-fat dairy consumption reduces systolic blood pressure, but does not improve other metabolic risk parameters in overweight and obese subjects. Nutr Metab Cardiovasc Dis 2011;21(5):355–61.
50. Wennersberg MH, Smedman A, Turpeinen AM, Retterstol K, Tengblad S, Lipre E, Aro A, Mutanen P, Seljeflot I, Basu S, et al. Dairy products and metabolic effects in overweight men and women: results from a 6-mo intervention study. Am J Clin Nutr 2009;90(4):960–8.
51. Van Loan MD, Keim NL, Adams SH, Souza E, Woodhouse LR, Thomas A, Witbracht M, Gertz ER, Piccolo B, Bremer AA, et al. Dairy foods in a moderate energy restricted diet do not enhance central fat, weight, and intra-abdominal adipose tissue losses nor reduce adipocyte size or inflammatory markers in overweight and obese adults: a controlled feeding study. J Obes 2011;2011:989657.
52. Bowen J, Noakes M, Clifton PM. Effect of calcium and dairy foods in high protein, energy-restricted diets on weight loss and metabolic parameters in overweight adults. Int J Obes 2005;29(8):957–65.
53. Gardner CD, Messina M, Kiazand A, Morris JL, Franke AA. Effect of two types of soy milk and dairy milk on plasma lipids in hypercholesterolemic adults: a randomized trial. J Am Coll Nutr 2007;26(6):669–77.
54. Rideout TC, Marinangeli CP, Martin H, Browne RW, Rempel CB. Consumption of low-fat dairy foods for 6 months improves insulin resistance without adversely affecting lipids or bodyweight in healthy adults: a randomized free-living cross-over study. Nutr J 2013;12:56.
55. Turner KM, Keogh JB, Clifton PM. Red meat, dairy, and insulin sensitivity: a randomized crossover intervention study. Am J Clin Nutr 2015;101(6):1173–9.
56. Barr SI, McCarron DA, Heaney RP, Dawson-Hughes B, Berga SL, Stern JS, Oparil S. Effects of increased consumption of fluid milk on energy and nutrient intake, body weight, and cardiovascular risk factors in healthy older adults. J Am Diet Assoc 2000;100(7):810–7.
57 Kratz M, Marcovina S, Nelson JE, Yeh MM, Kowdley KV, Callahan HS, Song X, Di C, Utzschneider KM. Dairy fat intake is associated with glucose tolerance, hepatic and systemic insulin sensitivity, and liver fat but not β-cell function in humans. Am J Clin Nutr 2014;99(6): 1385–96.
58 Fretts AM, Howard BV, McKnight B, Duncan GE, Beresford SAA, Mete M, Eilat-Adar S, Zhang Y, Siscovick DS. Associations of processed meat and unprocessed red meat intake with incident diabetes: the Strong Heart Family Study. Am J Clin Nutr 2012;95(3):752–8.