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Longitudinal association between dairy consumption and changes of body weight and waist circumference: the Framingham Heart Study

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Abstract

Background—Dairy foods are nutrient-dense and may be protective against long-term weight gain.

Objective—We aimed to examine the longitudinal association between dairy consumption and annualized changes in weight and waist circumference (WC) in adults.

Methods—Members of the Framingham Heart Study Offspring Cohort who participated in the 5th through 8th study examinations (1991–2008) were included in these analyses (3,440 participants with 11,683 observations). At each exam, dietary intake was assessed by a validated food frequency questionnaire, and weight and WC were assessed following standardized procedures. Repeated measures models were used for the longitudinal analyses by adjusting for time-varying or invariant covariates.

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Conflict of interest

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Authors' contributions to manuscript

1) Designed research (P.F.J and N.M.M.); 2) conducted research (P.F.J. and H.W.); 3) provided essential reagents or provided essential materials (J.B.M., C.S.F. and G.T.R.); 4) analyzed data or performed statistical analysis (H.W. and G.T.R.); 5) wrote paper (H.W. and P.F.J.); 6) had primary responsibility for final content (P.F.J.); 7) other: critical review (L.M.T., N.M.M., and C.S.F.).

Results—On average, participants gained weight and WC during follow-up. Dairy intake increased across exams. After adjusting for demographic and lifestyle factors (including diet quality), participants who consumed ≥ 3 servings/d of total dairy had 0.10 [±0.04] kg smaller annualized increment of weight ($P_{trend}=0.04$) than those consuming <1 serving/d. Higher total dairy intake was also marginally associated with less WC gain ($P_{trend}=0.05$). Similarly, participants who consumed ≥ 3 servings/wk of yogurt had a 0.10 [±0.04] kg and 0.13 [±0.05] cm smaller annualized increment of weight ($P_{trend}=0.03$) and WC ($P_{trend}=0.008$) than those consuming <1 serving/wk, respectively. Skim/low-fat milk, cheese, total high-fat or total low-fat dairy intake was not associated with long-term change of weight or WC.

Conclusion—Further longitudinal and interventional studies are warranted to confirm the beneficial role of increasing total dairy and yogurt intake, as part of a healthy and calorie-balanced dietary pattern, in the long-term prevention of gain in weight and WC.

Keywords

Dairy; Weight; Waist circumference; Longitudinal; Milk; Yogurt

Introduction

The prevalence of obesity has increased dramatically world-wide¹, including in the United States (U.S.)^{2,3}. Obesity, especially abdominal obesity (as indicated by a greater waist circumference (WC)), is a major risk factor for several chronic diseases, e.g. cardiovascular diseases (CVD)^{4,5}. Consequently, the obesity-associated medical costs have been increasing and accounted for almost 10% of the US national healthcare budget in 2008⁶. Since diet has been an important contributor to the current obesity epidemic⁷, it must also be part of the strategy for reversing trends in weight gain.

The possibility that consuming dairy products may influence body weight has been examined in a few prospective observational studies and randomized controlled trials (RCTs)^{8–11}. However, the evidence on a benefit of dairy for weight maintenance remains inconsistent and difficult to interpret. The RCTs, which are mostly short-term (i.e. up to several months) interventions, have primarily examined the effect of dairy consumption on weight loss as a part of energy-restricted diets, rather than weight maintenance^{9–11}. Recent reviews of RCTs found that dairy products only modestly facilitated weight loss in short-term, energy-restricted trials¹⁰. On the other hand, the prospective observational studies have examined the role of dairy consumption in long-term weight maintenance over years^{8,9}. Evidence has suggested that preventing long-term weight gain and even the weight maintenance after weight-loss pose a substantial challenge^{12,13}. Given the lack of long-term weight maintenance RCTs, prospective observational studies can be a valuable means to examine the role of dairy consumption in lifetime weight maintenance. Nonetheless, most of the previous cohort studies that examined dairy consumption and weight maintenance failed to account for the changes in dairy intake during follow-up or the influence of overall diet quality on the observed associations^{8,9}. In addition, the variation in dairy food type may also partially explain the observed inconsistent findings^{8,9}. For example studies have not shown consistent associations between high-fat dairy and weight maintenance^{8,14}, and fermented dairy products, although gaining increased interest in

relation to health^{15–18}, have been barely explored in long-term prospective studies of anthropometric measurements.

The present longitudinal study utilized data from an adult cohort with several repeated measurements on dietary intake (including overall diet quality) body weight and waist circumference (WC). We aimed to examine the association between consumption of different types of dairy products and long-term changes in weight and WC among American adults with an average follow-up of 13-years.

Subjects and Methods

Study population

The current study is based on longitudinal data from the National Heart, Lung, and Blood Institute (NHLBI) Framingham Heart Study (FHS) Offspring Cohort¹⁹. Briefly, the original FHS followed a cohort of US adults (aged 28–62 years at baseline) since 1948 to study CVD and its risk factors. In 1971, 5,124 offspring (aged 5–70 years) of the original FHS cohort were recruited to participate in the FHS Offspring Cohort Study. As of 2008, seven follow-up study examinations have been conducted with response rates of 75.4% (n=3,863), 75.6% (n=3,873), 78.4% (n=4,019), 74.1% (n=3,799), 68.9% (n=3,532), 69.1% (n=3,539) and 59.0% (n=3,021) for exam 2 to exam 8, respectively. At each exam, participants underwent a standardized medical history and physical examination, while dietary intakes were assessed since exam 5 (i.e. the baseline of the current study). For the present study, we used information gathered on participants from the 5th (1991–1995) through the 8th (2005–2008) study examinations. All study protocols and procedures were approved by the institutional review board for human research at Boston University. Written informed consent was obtained from all participants. The current study was approved by the institutional review board for human research at Tufts Medical Center.

Because the surviving cohort members may not attend all follow-up study examinations, to maximize the sample size and minimize potential selection bias, the current longitudinal analyses included 3,736 participants who attended at least two of the four examinations (exam 5 through 8). These participants contributed a total of 14,944 observations; but not all of these observations were complete or valid. Therefore, we first excluded 2,932 of 14,944 observations due to missing or invalid food frequency questionnaire (FFQ) data. An FFQ was deemed invalid if reported total energy intake of <600 kcal/d for all or >4,000 kcal/d for women and >4,200 kcal/d for men or >12 blank food items). Among the remaining 12,012 observations, we then excluded the missing observations of dairy consumption (n=1), body weight and WC (n=109) during follow-up. These exclusions resulted in 11,902 observations for 3,659 participants. After these exclusions, 219 participants had only one complete and valid observation. Because the annualized change of weight or WC could not be calculated for these 219 participants, they were also excluded from our final analyses, leaving 3,440 participants with 11,683 observations and a median follow-up time of 12.9 years in the current analyses. Participants who were excluded from the analyses were older and less healthy (e.g. higher cholesterol levels, blood pressure) than those who remained in the analyses.

Ascertainment of exposures and outcomes

Dietary assessments—Starting at the 5th exam, a 126-item semi-quantitative FFQ²⁰ was mailed to every participant before their exam. Participants were asked to bring the completed FFQ with them at their FHS exam visit. The validity of the FFQ has been reported previously^{20–22}. For dairy products, the correlations between intakes assessed by FFQ and by diet records were 0.81 for skim/low-fat milk, 0.62 for whole milk, 0.73 for ice-cream, 0.80 for cottage cheese, 0.57 for hard cheese, and 0.94 for yogurt^{22, 23}. The FFQ queried participants on how often, on average, during the past year they consumed a standardized serving size of each food (e.g. 1 cup of yogurt; one 8oz glass of skim or low fat milk; etc.). There were nine frequency categories ranging from “never or less than one serving per month” to “more than six servings per day”. For each food, if participants reported consuming “never or less than one serving per month”, their intake of this food was coded as zero servings/wk in the FFQ database. If participants reported consuming “1–3 servings per month” or more of this food, their intake of this food was converted to “servings/week”. Separate questions also assessed the use of vitamin and mineral supplements, the types of breakfast cereal and cooking oil, and the information about certain cooking and eating behaviors. The daily nutrient values were calculated by multiplying the nutrient content of the specific portion size of each food (based on the Harvard nutrient database) by the daily consumption frequency, and summing across all food items.

The dairy foods included in the current study were: skim or low-fat milk, whole milk, cream (e.g., coffee, whipped), sour cream, sherbet or ice milk, ice cream, yogurt, cottage or ricotta cheese, cream cheese, and other cheese (e.g., American, cheddar, etc.). For the data analyses, dairy foods were coded and the nutrient components were calculated according to USDA Nutrient Database²⁴. We created a new variable for the total dairy consumption by summing the servings per week of all the dairy foods. Additionally, the high-fat dairy group includes whole milk, ice-cream, cream and sour cream, and all cheese; and the low-fat dairy group included skim/low-fat milk, yogurt and sherbet/ice milk.

The Dietary Guidelines Adherence Index (DGAI), created to assess the adherence of participants to the key dietary recommendations by the 2005 Dietary Guidelines for Americans²⁵, was used as a measure of overall diet quality among participants.

Anthropometric measurements—Height (to the nearest 0.25 inches) and weight (to the nearest 0.5 lbs) were measured at the physical examination with the participant standing, shoes off, and wearing only a hospital gown. Scale was calibrated daily. Body mass index (BMI) was then calculated in kg/m². WC was measured by a trained professional by applying anthropometric tape at the level of the umbilicus, underneath the gown; recording the reading at mid-respiration with participant breathing normally; and rounding down to the nearest 0.25 inches.

Measurements of other variables

Standardized physical exam was conducted and questionnaires were used to assess participants' lifestyle behaviors and medical history. Physical activity was determined as the number of hours spent performing specific activities (i.e., sleep, sedentary, slight activity,

moderate activity and heavy activity) on a typical day. A physical activity index (PAI), expressed in metabolic equivalents (METs), was calculated by assigning each activity category a MET value based on the oxygen consumption required to perform activities in the category²⁶ and deriving a weighted average of the MET values based on the proportion of time spent on activities in each category. PAI was not available for exams 6, and thus values from exams 5 were carried forward.

Sitting blood pressure was measured twice on each participant after a 5-minute rest using a random-zero sphygmomanometer and the two readings were averaged for the analyses. Fasting (8 hours) blood samples were drawn for assessing the levels of glucose and lipids. A hexokinase/glucose-6-phosphate dehydrogenase method²⁷ was used to measure serum glucose. Plasma total cholesterol and triglycerides were measured by enzymatic methods²⁸, and HDL cholesterol was measured after dextran-magnesium precipitation²⁹. Fasting insulin concentrations were measured using radioimmunoassay³⁰. For glucose, triglyceride, total cholesterol and HDL cholesterol, the intra- and inter-assay coefficients of variation were all <2% and <3%, respectively; for fasting insulin, the intra-assay coefficient of variation was 3.9%, and the interassay coefficient of variation ranged 4.7–6.1%¹⁷.

Statistical analysis

All analyses were conducted separately for weight and WC with SAS statistical software (version 9.2; SAS Institute, Cary, NC). Mean values or percentage of participants' characteristics were calculated and compared for exams 5 through 8. The longitudinal association between dairy consumption and the change of weight and WC was examined within exam-intervals over a 13-year follow-up.

Estimated dairy consumption and other dietary factors—The consumption of dairy foods was represented in servings/week, except for total dairy intake which was expressed in servings/d (i.e., calculated by dividing the values of “servings per week” by 7). To estimate the usual dairy consumption within each exam-interval, we averaged the dairy consumption reported at the beginning and the end of the interval (i.e., at two exams). This was to better capture the long-term dietary intake and minimize potential systematic errors in dietary assessment. Based on their consumption of each dairy food or dairy group, participants were then further categorized into three groups: <1 servings, 1 to 3 servings, and 3 servings per day for total dairy intake or per week for other dairy foods/groups.

The average intake of total calories and food groups (i.e., fish, meat, whole grain, refined grain, and fruits and vegetables), as well as the average DGAI score within each exam-interval, were also estimated in a similar way as described above.

Annualized change of weight and waist circumference—Measurements of weight and WC were converted to kilograms (kg) and centimeters (cm), respectively. The changes in weight and WC within exam-intervals were calculated separately for each participant as the difference between two adjacent measurements. We used annualized change as the outcome variables for the current analyses to correct for the unequal time intervals between exams.

Dairy consumption and annualized change of weight and waist circumference

—We used repeated-measure regressions (PROC MIXED) to examine the longitudinal association between dairy consumption and annualized change of weight and WC within exam-intervals across 13-years of follow up. An unstructured variance structure was specified.

In a secondary analysis, we defined the gain or the loss of weight or WC as an absolute change of >0.25kg or 1cm between two consecutive exams based on the measurement accuracy that the scales could achieve (i.e., 0.5 lbs for weight and 0.25 inches for WC). Participants were then categorized into nine non-exclusive groups accordingly. We found that participants were not consistently and simultaneously gaining weight and WC within each exam-interval during follow-up. Therefore, in addition to the analyses conducted among total sample, we also performed subgroup analyses excluding discordant values for gains in weight and waist circumference. Specifically, for the analysis of weight change, we excluded the observations of participants who gained WC but not weight within the same time interval, while for the analysis of WC change, we excluded the observations of participants who gained weight but not WC.

The mixed models were adjusted, as appropriate, for time-varying factors (including measurements of weight or WC, age, smoking status, physical activity, blood pressure, diabetic status, cholesterol-lowering medication use and levels of blood lipids at the beginning of each exam interval; and average total energy intake and DGAI score within each exam interval), and the time-invariant factor (i.e. sex). The interactions between dairy consumption and both sex and BMI ($BMI > 25 \text{ kg/m}^2$ vs. 25 kg/m^2) at the beginning of exam intervals were tested by including the corresponding cross-product terms in the separate mixed models for each term and assessing the statistical significance of the likelihood ratios. However, no interactions were observed for sex or BMI status (data not shown).

All statistical tests were two-sided. Statistical significance was set at $P < 0.05$.

Results

Table 1 shows participants' characteristics by examination cycle. The mean [\pm SD] age of the participants at baseline was 54.5 [\pm 9.6] years (range 26–84 years). Participants tended to quit smoking and become diabetic as they aged. The levels of total cholesterol and triglycerides appeared to be lower with age, while HDL-cholesterol appeared to be higher at later exams compared to exam 5. These changes are consistent with the striking increase in the prevalence of cholesterol-lowering medication use across exams. In contrast, although there were more people using anti-hypertension medication and diastolic blood pressure appeared to be well-controlled (i.e. mean < 80 mmHg) across exams, the mean systolic blood pressure was high at all examinations.

Total dairy consumption and most dairy categories tended to be higher at exam 8 compared to exam 5, while the intake of total low-fat dairy and the skim/low-fat milk tended to decline over time (Table 1). The mean [\pm SD] weight and WC were greater at exam 8 than at exam

5, while the rate of weight and WC change appeared to decrease across exam intervals (Table 2).

As shown in Table 3, among all participants, higher total dairy consumption was associated with smaller annualized gain in weight ($P_{trend}=0.04$), adjusting for demographic and lifestyle factors (including overall diet quality as represented by the DGAI score). In multivariate models, the mean body weight increased at a rate of 0.10 [± 0.03] kg/year among participants who consumed 3 servings/d or more of total dairy, as compared to a rate of 0.20 [± 0.03] kg/year among those who consumed <1 serving/d of total dairy. However, except for yogurt, the intakes of dairy product sub-categories were not related to the long-term weight change (all $P_{trend}>0.05$). Participants who consumed 3 servings/wk of yogurt had more than 50% smaller weight gain than those reported consuming <1 serving/wk (0.07 \pm 0.04 vs. 0.16 \pm 0.02, $P_{trend}=0.03$).

The associations between dairy and WC were consistent with those seen for weight change (Table 4). We observed that individuals who consumed three or more servings/d of dairy had an annual rate of WC increase that was 15% less than the annualized WC change among those who consumed less than 1 serving/d ($P_{trend}=0.05$). Individuals who consumed 3 servings of yogurt per week had gained about 20% less WC per year than those consumed less than one serving of yogurt per week ($P_{trend}=0.008$). As with weight gain, we observed no significant downward trend of WC change across the consumption groups of any other dairy product sub-categories.

Similar results were observed in the subgroup analyses in which participants who gained WC but not weight or gained weight but not WC within exam-intervals were excluded as described above (data not shown).

In all analyses presented above, we additionally adjusted for diabetic status, systolic blood pressure, cholesterol-lowering medication use, and/or blood lipid profile. However, none of these factors significantly influenced the findings. Similar results were also found when we adjusted for individual food groups (e.g. fish, meat, whole grains, fruits, vegetables and mutually exclusive dairy foods) instead of overall diet quality.

Discussion

Among FHS participants, we observed the expected overall upward trend of weight and WC during an average of 13-years of follow-up. After adjustment for demographic and lifestyle factors (including overall diet quality), greater consumption of total dairy products and yogurt, but not other dairy product sub-categories, was associated with less gain in weight and WC. Body weight and WC typically fluctuate over time, but tend to increase with age^{31,32}, a phenomenon evident in our study. The tendency of age-related weight gain is superimposed upon the world-wide trends in weight gain and obesity³¹. These trends may come with serious health consequences as even moderate weight increases over long-term have been seen to significantly increase risk of mortality and CVD³³⁻³⁵. However, it is noteworthy that the magnitude of weight and WC increments attenuated over time in the current FHS

population. This is consistent with previous evidence among older populations, and may be due to a shorter life expectancy among obese people^{31,32}.

The beneficial role of dairy products on obesity prevention has been previously explored. These earlier findings suggested that habitual dairy intake may protect against weight gain^{8,10,36}, especially in short-term and along with calorie restriction¹⁰. However, long-term prospective evidence among free-living populations or in RCTs without energy restriction is inconsistent^{8,10}. The current analysis suggests an inverse association between total dairy consumption and long-term gain in body weight and WC. This is concordant with the findings of Pereira et al. in which increasing daily consumption of total dairy by one serving per day was associated with 18% lower risk of obesity among American adults³⁷. However, other longitudinal studies reported either null or a positive relation in this regard⁸. Type of dairy foods may play a critical role in explaining the discrepancy⁸.

Increasing low-fat and fat-free dairy products have been recommended in the Dietary Guidelines for Americans for achieving nutrient adequacy, disease prevention and overall good health⁷. However, we observed no beneficial relation of total low-fat dairy or skim/low-fat milk with long-term change of weight or WC. Nonetheless, we did find that participants who consumed 3+ servings of yogurt per week had significantly smaller gain in body weight and WC than those who consumed less than one serving per week. Among the few prospective studies that investigated yogurt, the finding of Mozaffarian et al.³⁸ is in agreement with ours. It was reported that, among over 120,000 U.S. men and women, there was approximately 0.37kg less 4-year weight gain with each additional serving of yogurt intake per day; while no association was found for low-fat or skim milk. In contrast, by following a cohort of young adults for 10 years, Pereira et al. found no association between yogurt and incident obesity among those who were overweight at baseline³⁷. Some studies even reported a potential adverse impact of yogurt intake on weight and WC^{39,40}.

Previously, we have found that yogurt intake was independently associated with higher nutrient adequacy in the FHS cohort¹⁷. Some of the nutrients, such as calcium, have been shown to contribute to the weight-control effect of dairy products⁴¹, such as aiding in loss of weight, body fat, and trunk fat during caloric restriction^{42,43}. Although low-fat yogurt possesses similar nutrition components as skim/low-fat milk, it is more highly concentrated for some water-soluble vitamins and minerals²⁴. The amount of potassium, calcium, and magnesium in 8oz low-fat yogurt is approximately 1.5 times than that in an equal serving size of low-fat milk²⁴. Moreover, yogurt may facilitate the calcium bioavailability because of its acidity⁴⁴. In addition, as a fermented product from milk, yogurt contains abundant probiotics, whey and casein proteins and bioactive peptides. These nutritional components may beneficially affect human gut microbiota which moderate energy homeostasis by fermenting indigestible polysaccharides to regulate energy extraction and uptake; or by producing, stimulating or activating signaling molecules and hormones that are involved in human metabolism to modify gut function^{45,46}. These mechanisms may explain a potential role of yogurt in facilitating weight management^{45,46}. Dairy as a food has been found to confer greater anti-obesity effect than calcium supplements⁴¹, indicating the potential for synergistic effects of different dairy nutritional components.

We did not find that the long-term change of weight was greater among participants who consumed more high-fat dairy products; while the individuals who consumed 3 servings per week of high-fat dairy products tended to gain less WC than those who consumed <3 servings per week (data not shown). The health impacts of full/high-fat dairy have been prosperously debated^{14, 37, 47, 48}. In addition to the potential for better dietary patterns associated with dairy consumption, the conjugated linoleic acid in dairy fats may help reduce body fat and increase lean body mass^{49, 50}. There is also limited evidence that another fatty acid unique to dairy and ruminant fat, pentadecanoic acid (15:0 fatty acid), is associated with body weight and BMI⁵¹. However, pentadecanoic acid is highly correlated with dairy intake⁵¹, and unlike conjugated linoleic acid, there are no intervention or experimental studies that have examined its effects on health parameters, including weight, independent of dairy intake.

According to some previous studies, the beneficial effect of dairy intake may be more significant among overweight or obese people^{37, 39, 52}. Similarly, because men and women are known to differ in energy metabolism, body fat distribution, and dietary consumption behaviors, a gender difference was also reported previously on the association between yogurt intake and weight control³⁹. However, we failed to find any interactions between dairy intake, gender or/and baseline anthropometric status in relation to long-term change of weight or WC.

Strengths of the present study included its prospective design with long follow-up and repeated assessments on both usual dietary intakes and anthropometric measurements. A variety of dairy foods were considered in the current study. Before RCTs can be conducted in a long-term, cost-effective manner, observational cohort studies, such as our current study, remain clinically important in examining the role of dairy consumption on lifetime weight maintenance. Although there are limitations associated with use of the FFQ in assessing dietary intake, dairy intake assessed by the current FFQ has relatively high validity^{22, 23}. We have accounted for participants' overall dietary quality; and several factors that may be linked to the change of dietary intake were also controlled, e.g. medication use and metabolic profile. Nevertheless, the fact that the FFQ did not differentiate some dairy foods (e.g. all types of yogurt were generalized as low-fat) will result in the misclassification of the fat intake from some dairy foods, which limits our ability to observe relations based on dairy fat contributions. The generalizability of our findings is also limited as participants were middle aged and older, Caucasian American adults, largely of European descent. Because of the differences in age and health status between participants who were excluded from the analyses and those who remained, our findings may be bias although the direction is unknown. Finally, it is possible that the modest associations observed with total dairy and yogurt were the result of residual confounding by latent healthy lifestyle factors that we were not able to identify.

In conclusion, we found that greater total dairy and yogurt consumption were associated with smaller long-term gain in weight and WC among American adults, controlling for total energy intake and healthier dietary choices and lifestyle. Although the lower magnitude of the gain in weight and WC per year associated with total dairy and yogurt consumption appeared to be small, the potential benefits of total dairy and yogurt consumption may be

significant over the long term. Interestingly, the observed significance of total dairy products may be primarily attributed to yogurt, since excluding yogurt from total dairy products resulted in similar but non-significantly inverse associations with the change of weight and WC (data not shown). Yogurt intake is relatively low in U.S. populations^{53, 54}, including the current FHS cohort, especially compared to European populations. If there is an observable relation between yogurt consumption and weight and WC gains in populations with relatively low intakes, efforts to increase consumption of yogurt among American adults as a component of an energy-balanced, healthy dietary pattern may serve as an effective dietary tool for management of weight gain and obesity prevention. However, we cannot assume any causal effect of yogurt consumption on weight and WC based on observational methodology, and it is too soon to speculate on any specific recommendations of yogurt intake for American adults. To this end, future long-term interventions are warranted to assess potential benefits of yogurt. The underlying mechanisms for the possible beneficial role of yogurt also deserve greater investigation.

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Abbreviations

CVD	Cardiovascular disease
WC	Waist circumference
RCT	Randomized clinical trial
NHLBI	National Heart, Lung, and Blood Institute
FHS	Framingham Heart Study
U.S.	United States
USDA	U.S. Department of Agriculture
FFQ	food frequency questionnaire
DGAI	Dietary Guidelines Adherence Index
PAI	Physical activity index
MET	Metabolic equivalents
BMI	Body Mass Index
SD	Standard Deviation

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Table 1

Characteristics of participants (Mean±SD or percentage) by exams (11,683 observations for 3,440 participants) ^a

	Exam 5: 1991–1995	Exam 6: 1995–1998	Exam 7: 1998–2001	Exam 8: 2005–2008
Number of participants	3,099	3,049	2,944	2,591
Age (years)	54.5±9.6	58.6±9.6 <i>b,d</i>	61.1±9.4 <i>b,d</i>	66.4±8.9 <i>b,d</i>
Men (%)	46.4	46.9 <i>b,d</i>	45.8	45.0
BMI (kg/m ²)	27.4±4.9	27.9±5.1 <i>b,d</i>	28.1±5.3 <i>b,d</i>	28.2±5.3 <i>b,d</i>
Regular cigarette smokers (%)	18.6	15.0 <i>b,d</i>	12.5 <i>b,d</i>	8.5 <i>b,d</i>
Physical activity index	34.9±6.3	35.1±6.3	37.4±6.4 <i>b,d</i>	37.2±6.4 <i>d</i>
DGAI score	9.2±2.7	9.6±2.7 <i>b,d</i>	9.4±2.7 <i>b,d</i>	9.5±2.8 ^d
Total cholesterol (mg/dL)	204.8±36.7	206.1±40.2	200.6±36.6 <i>b,d</i>	186.2±37.3 <i>b,d</i>
HDL-cholesterol (mg/dL)	50.2±15.1	51.2±16.2 <i>b,d</i>	54.0±16.9 <i>b,d</i>	57.4±18.0 <i>b,d</i>
Triglycerides (mg/dL)	146.9±111.3	141.3±134.5 <i>b,d</i>	135.06±82.4 <i>d</i>	117.6±68.4 <i>b,d</i>
Glucose (mg/dL)	100.2±27.0	103.4±27.3 <i>b,d</i>	103.9±25.7 <i>b,d</i>	106.0±22.1 ^{b,d}
Systolic blood pressure (mmHg)	125.8±18.6	128.5±18.8 <i>b,d</i>	127.3±18.8 <i>c,d</i>	128.3±17.0 <i>d</i>
Diastolic blood pressure (mmHg)	74.7±10.0	75.5±9.5 <i>b,d</i>	74.0±9.7 <i>b,d</i>	73.5±10.0 <i>b,d</i>
Diabetics (%)	6.5	9.5 <i>b,d</i>	10.9 <i>d</i>	11.7 <i>d</i>
Hypertension medication users (%)	18.1	28.2 <i>b,d</i>	34.5 <i>b,d</i>	49.5 <i>b,d</i>
Cholesterol-lowering meds users (%)	7.3	13.9 <i>b,d</i>	20.9 <i>b,d</i>	45.3 <i>b,d</i>
Dietary intake				
Total calories (kcal)	1875±622	1852±616 <i>c,e</i>	1828±594 ^{b,d}	1876±634 <i>b</i>
Fish (servings/week)	2.30±1.94	2.13±1.74 <i>b,d</i>	2.23±1.84 ^b	2.33±1.99
Meat (servings/week)	9.39±5.57	9.08±5.39 <i>b,d</i>	9.37±5.70 <i>b</i>	9.99±5.85 <i>b,d</i>
Whole grain (servings/week)	8.87±8.81	8.21±8.15 <i>b,d</i>	8.22±8.15 <i>d</i>	8.96±7.86 ^b
Refined grain (servings/week)	14.21±12.05	13.90±11.86	12.39±10.92 ^{b,d}	9.44±9.06 ^{b,d}
Fruits and vegetables (servings/week)	28.29±17.35	29.06±16.98 ^{b,d}	29.57±17.33 ^d	30.23±17.81 ^d
Dairy intake				
Total dairy (servings/day)	1.93±1.49	1.93±1.46	1.96±1.45 ^d	2.08±1.53 ^{b,d}
High-fat dairy (servings/week)	6.55±8.25	6.24±7.66	6.41±7.49 <i>c,e</i>	7.26±8.13 <i>b,d</i>
Low-fat dairy (servings/week)	6.00±6.55	6.26±6.71 <i>c,e</i>	6.15±6.74	5.92±6.38 <i>c</i>
Skim/low-fat milk (servings/week)	4.83±6.01	4.89±6.08	4.80±5.94	4.29±5.37 ^{b,d}
Yogurt (servings/week)	0.86±1.84	1.01±2.07 ^{b,d}	1.02±2.20 ^d	1.35±2.92 ^{b,d}
Cheese (servings/week)	3.12±3.35	3.15±3.40	3.46±3.87 ^{b,d}	4.04±4.35 <i>b,d</i>

^aComparisons between groups were tested by paired t-test or sign rank test (with Bonferroni correction) for continuous variables, or by chi-square test for categorical variables;

^bP-values<0.01 for comparing to the previous exam;

^cP-values<0.05 for comparing to the previous exam;

^dP-values<0.01 for comparing to exam 5;

^eP-values<0.05 for comparing to exam 5;

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Table 2Body weight and waist circumference (Mean±SD) by exams (11,683 observations for n=3,440 participants) ^a

	Exam 5: 1991–1995	Exam 6: 1995–1998	Exam 7: 1998–2001	Exam 8: 2005–2008
Number of participants	3,099	2,049	2,944	2,591
Weight (kg)	77.5±16.6	78.7±17.1 <i>b,d</i>	79.1±17.4 <i>b,d</i>	78.9±17.7 <i>d</i>
Annualized weight change (kg/year)	--	0.27±1.29 <i>f</i>	0.13±1.81 <i>c,f</i>	0.00±0.99 <i>c</i>
Waist circumference (cm)	92.5±14.2	97.6±13.6 <i>b,d</i>	99.8±14.1 <i>b,d</i>	101.4±14.4 <i>b,d</i>
Annualized waist change (cm/year)	--	1.23±1.89 <i>f</i>	0.81±2.02 <i>c,f</i>	0.35±1.04 <i>c,f</i>

^aComparisons between groups were tested by paired t-test or sign rank test (with Bonferroni correction) for continuous variables, or by chi-square test for categorical variables;

^bP-values<0.01 for comparing to the previous exam;

^cP-values<0.01 for comparing to the previous exam interval;

^dP-values<0.01 for comparing to exam 5;

^eP-values<0.05 for comparing to exam 5;

^fP-values<0.01 for difference from zero;

Table 3

Annualized change of weight across groups of dairy consumption (11,683 observations for 3,440 participants)

	Dairy consumption groups			<i>P</i> _{trend}
	<1 servings	1 - < 3 servings	3 servings	
Total dairy (servings/day)	0.67 (0, 0.998) ^a	1.75 (1.00, 3.00)	3.70 (3.01, 12.32)	
N ^b	1873	4865	1505	
Age-adjusted Model	0.17±0.03 ^c	0.11±0.02	0.09±0.03	0.05
Multivariate model ^d	0.20±0.03	0.14±0.02	0.10±0.03	0.04
High-fat dairy (servings/week)	0.50 (0, 0.97)	2.00 (1.00, 2.99)	6.47 (3.00, 84.47)	
N	900	1916	5427	
Age-adjusted Model	0.12±0.04	0.16±0.03	0.11±0.01	0.23
Multivariate model	0.15±0.04	0.19±0.03	0.13±0.02	0.17
Low-fat dairy (servings/week)	0.24 (0, 0.97)	1.97 (1.00, 2.99)	7.00 (3.00, 49.24)	
N	1674	1229	5340	
Age-adjusted Model	0.12±0.03	0.17±0.03	0.11±0.02	0.30
Multivariate model	0.13±0.03	0.20±0.04	0.14±0.02	0.77
Skim/low-fat milk (servings/week)	0 (0, 0.74)	1.74 (1.00, 2.99)	6.25 (3.00, 42.00)	
N	2403	1248	4592	
Age-adjusted Model	0.11±0.02	0.12±0.03	0.13±0.02	0.70
Multivariate model	0.13±0.03	0.15±0.04	0.16±0.02	0.33
Yogurt (servings/week)	0 (0, 0.74)	1.74 (1.00, 2.99)	3.74 (3.00, 24.50)	
N	5720	1432	1091	
Age-adjusted Model	0.14±0.01	0.12±0.03	0.02±0.03	0.002
Multivariate model	0.16±0.02	0.15±0.03	0.07±0.04	0.03
Cheese (servings/week)	0.71 (0, 0.97)	2.00 (1.00, 2.99)	4.50 (3.00, 42.94)	
N	1627	2781	3835	
Age-adjusted Model	0.12±0.03	0.14±0.02	0.11±0.02	0.66
Multivariate model	0.14±0.03	0.16±0.03	0.14±0.02	0.79

^aMedian intake (range) for all such values^bN: number of observations of the change of body weight^cMean±SE annualized weight change (kg/year) for all such values^dModel adjusted for sex and time-varying variables including age, smoking status, physical activity, and weight at the beginning of each exam interval, and average total energy intake and DGAI score during each exam-interval.

Table 4

Annualized change of waist circumference across groups of dairy consumption (11,683 observations for 3,440 participants)

	Dairy consumption groups			<i>P</i> _{trend}
	<1 servings	1- < 3 servings	3 servings	
Total dairy (servings/day)	0.67 (0, 0.998) ^a	1.75 (1.00, 3.00)	3.70 (3.01, 12.32)	
N ^b	1873	4865	1505	
Age-adjusted Model	0.72±0.03 ^c	0.65±0.02	0.64±0.03	0.12
Multivariate model ^d	0.75±0.04	0.68±0.02	0.64±0.04	0.05
High-fat dairy (servings/week)	0.50 (0, 0.97)	2.00 (1.00, 2.99)	6.47 (3.00, 84.47)	
N	900	1916	5427	
Age-adjusted Model	0.64±0.05	0.72±0.03	0.65±0.02	0.17
Multivariate model ^c	0.69±0.05	0.76±0.04	0.66±0.02	0.03
Low-fat dairy (servings/week)	0.24 (0, 0.97)	1.97 (1.00, 2.99)	7.00 (3.00, 49.24)	
N	1674	1229	5340	
Age-adjusted Model	0.66±0.03	0.72±0.04	0.65±0.02	0.45
Multivariate model ^c	0.68±0.04	0.72±0.04	0.68±0.02	0.75
Skim/low-fat milk (servings/week)	0 (0, 0.74)	1.74 (1.00, 2.99)	6.25 (3.00, 42.00)	
N	2403	1248	4592	
Age-adjusted Model	0.66±0.03	0.68±0.04	0.66±0.02	0.90
Multivariate model ^c	0.67±0.03	0.69±0.04	0.69±0.03	0.53
Yogurt (servings/week)	0 (0, 0.74)	1.74 (1.00, 2.99)	3.74 (3.00, 24.50)	
N	5720	1432	1091	
Age-adjusted Model	0.68±0.02	0.68±0.04	0.58±0.04	0.06
Multivariate model ^c	0.71±0.02	0.70±0.04	0.57±0.04	0.008
Cheese (servings/week)	0.71 (0, 0.97)	2.00 (1.00, 2.99)	4.50 (3.00, 42.94)	
N	1627	2781	3835	
Age-adjusted Model	0.64±0.04	0.68±0.03	0.66±0.02	0.98
Multivariate model ^c	0.67±0.04	0.71±0.03	0.67±0.03	0.65

^a Median intake (range) for all such values

^b N: number of observations of the change of body weight

^c Mean±SE annualized change of waist circumference (cm/year) for all such values

^d Model adjusted for sex and time-varying variables including age, smoking status, physical activity, and waist circumference at the beginning of each exam interval, and average total energy intake and DGAI score during each exam-interval.