Low Dairy Intake in Early Childhood Predicts Excess Body Fat Gain

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Abstract

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Objective: To estimate the effect of dairy intake in early childhood on the acquisition of body fat throughout childhood.

Research Methods and Procedures: Ninety-nine of the original 106 families enrolled in the Framingham Children's Study with a child age to 6 years at baseline were followed into adolescence through yearly clinic visits and periodic data collection throughout each year. Dairy intake for these analyses was derived from a mean of 15 days of diet records per subject collected before age 6. A trained examiner took two measurements each year of height, weight, and triceps, subscapular, suprailiac, and abdominal skinfolds using a standardized protocol. Yearly change in body fat was estimated as the slope of these anthropometry measures from ages 5 to 13 years. Early adolescent body fat was estimated as the mean of all available measurements from 10 to 13 years of age.

Results: Children in the lowest sex-specific tertile of dairy intake during preschool (i.e., <1.25 servings per day for girls and <1.70 servings per day for boys) had significantly greater gains in body fat during childhood. These children with low dairy intakes gained more than 3 additional mm of subcutaneous fat per year in the sum of four skinfold measures. By the time of early adolescence, those in the lowest tertile of dairy intake had a BMI that was approximately two units higher and an extra 25 mm of subcutaneous fat.

Discussion: Suboptimal dairy intakes during preschool in this cohort were associated with greater gains in body fat throughout childhood.

Key words: dairy products, weight, adiposity, children, longitudinal study

Introduction

The rates of obesity among children and adults in the United States have been rising for more than 30 years (1–3). Recent evidence suggests that 65% of U.S. adults are either overweight or obese (4). Data from the 1999 to 2000 National Health and Nutrition Examination Survey indicate that 16% of children and adolescents, ages 6 through 19 years, are overweight (5). The acquisition of excess body fat during childhood is of particular concern because overweight children and adolescents are much more likely to become overweight adults (6) and are at higher risk for subsequent high blood pressure and lipid and insulin abnormalities (7,8).

The hypothesis that dairy consumption may be associated with weight regulation goes back to 1984 when McCarron et al. (9) noted an inverse association between calcium intake and body weight among subjects in the first National Health and Nutrition Examination Survey cohort. Animal studies have lent additional support to the idea that increasing dietary calcium among those on a low-calcium diet can suppress the lipogenic mechanisms associated with increases in circulating calcitrophic hormones (10–12). A number of studies of calcium intake among adults have concluded that there is an inverse association between calcium intake and adiposity (13–15), although at least one review of randomized trials that were designed originally to study calcium effects on bone density concluded that there is little evidence to support a beneficial effect of calcium or dairy intake on body fat (16). There have been several randomized clinical trials designed to look specifically at calcium and dairy intake and body weight or fat (17–20). Those studies suggest that calcium supplementation in the form of dairy foods leads to significantly greater weight and fat loss among obese subjects on a weight loss diet whose levels of calcium were low at baseline. Another randomized

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trial of dairy calcium among healthy, normal-weight women had neither an adverse, nor a beneficial, effect on body fat (21).

Although adult studies have focused on the role of dairy in weight loss, the focus of most studies of children is whether dairy has an etiologic role in the development of obesity. Because milk is an energy-dense food, it is possible that higher intake levels might be associated with increased weight or body fat gain during childhood. Several studies, however, have found no adverse effect of higher milk consumption levels on the amount of stored body fat in children (22–26). Data from an Italian lifestyle survey found that milk consumption among 5- to 11-year-old children was associated with lower BMI *z* scores (27). A longitudinal study of preschool-aged children found that those consuming more servings per day of dairy, irrespective of total calorie intake, had significantly lower levels of body fat through 8 years of age (28,29). In a Kaiser-Permanente study, the amount of calcium in one serving of milk was associated with a 0.78-mm reduction in iliac skinfold (SF)[1] thickness, whereas calcium from non-dairy sources had no effect (30). However, a recent review concluded that the majority of studies in children, including clinical trials, to date, do not support a protective effect of calcium and/or dairy on the risk of obesity (31). We used data from the prospective Framingham Children's Study to estimate the effect of dairy intake in early childhood on the changes in body fat from 5 to 13 years of age.

Research Methods and Procedures

The Framingham Children's Study is a longitudinal study of factors related to the development of dietary habits and physical activity patterns during childhood. In 1987, 106 two-parent families with a 3- to 6-year-old child were enrolled. Boys represented ~60% of the sample. The parents and children were examined annually from 1987 to 1999. During the yearly clinic visits, parents completed detailed questionnaires and interviews about their own health, activity, dietary habits, attitudes, beliefs, other risk behaviors, and also provided data on the child's diet and activity. Children were interviewed separately about their diet, activity, attitudes, and beliefs.

At each yearly clinic exam, weight (to the nearest 0.25 pound) was measured using a standard counterbalance scale, and height was measured (to the nearest 0.25 inch) using a measuring bar on the same scale. BMI was calculated as weight in kilograms divided by height in meters squared. The examiner used Lange calipers and a standard protocol to take two measures each of triceps, subscapular, suprailiac, and abdominal SFs for each child. When the two measures differed by 2 mm or more, two additional measures were taken.

Data on the following potential confounding factors were collected and examined: mother's age, education level, and BMI (in a subanalysis), and the child's age, sex, physical activity (Caltrac counts per hour), television viewing (hours per day), total energy intake (kilocalories per day), percent of energy from fat and/or saturated fat, and other dietary factors. Physical activity was assessed using an electronic motion sensor (Caltrac accelerometer; Muscle Dynamics, Torrance, CA); the children were asked to wear it for 3 to 5 consecutive days on one to four separate occasions each year. The device, which has been shown to provide valid estimates of physical activity in children (32,33), was programmed to provide unitless activity counts as a means of estimating the average number of activity counts per hour at each age. Television viewing time was assessed yearly by questionnaire.

Detailed dietary intake for each child was assessed repeatedly using 3-day diet records. To obtain stable estimates of baseline dietary intake, four sets of 3-day diet records were collected during the 1st year of the study. In each subsequent year, one or two sets of 3-day records were collected. During the early years of the study, parents completed all diaries for the children as well as their own diaries. The study nutritionist instructed each family in the completion of the diaries, including how to use common household measures to estimate portion sizes. In later years, the child assisted in the collection of the dietary data.

We used the Nutrition Data System of the University of Minnesota (34) to calculate mean intakes of macro- and micronutrients. We then estimated each child's daily intake of dairy and other foods using the U.S. Department of Agriculture's Food Guide Pyramid serving definitions (35). The milk or dairy group consists of milk, yogurt, and cheese; one serving is defined as a cup of milk or yogurt, 1.5 ounces of natural cheese, or 2.0 ounces of processed cheese. For other cheeses (e.g., cottage cheese, cream cheese), a serving is defined as the amount of the food that provides about the same amount of calcium as a cup of milk.

We combined data from the child's food records with the Food Pyramid serving database available through the technical files of the U.S. Department of Agriculture's Continuing Survey of Food Intake by Individuals (36). To do this, we matched the Continuing Survey of Food Intake by Individuals foods with foods in the Nutrition Data System by linking their food codes. In cases in which information on composite foods was insufficient to make an exact match, we compared the nutrient content data along with recipes and ingredients to determine the appropriate food servings for each food component.

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[1] Nonstandard abbreviations: SF, skinfold; CLA, conjugated linoleic acid.

Table 1. Baseline characteristics according to dairy intake during preschool

Characteristics	Sex-specific tertile of child's dairy intake at 3 to 6 years of age*		
	Tertile 1 (n = 30): 18 boys, 12 girls (mean ± SD)	Tertile 2 (n = 31):19 boys, 12 girls (mean ± SD)	Tertile 3 (n = 31): 19 boys, 12 girls (mean ± SD)
Children			
BMI (kg/m^2)	16.3 ± 1.0	16.1 ± 1.3	16.3 ± 1.1
Sum of four SFs (mm)	25.8 ± 5.7	26.2 ± 7.3	28.9 ± 8.0
Activity (Caltrac)	10.6 ± 1.5	11.0 ± 2.0	11.3 ± 2.0
Television (hours)	2.1 ± 0.9	1.9 ± 0.9	2.2 ± 1.1
Mothers			
Age	33.5 ± 4.1	32.7 ± 4.8	31.7 ± 4.6
BMI (kg/m^2)	24.8 ± 4.7	24.3 ± 4.3	24.3 ± 4.4
Activity (Caltrac)	5.7 ± 1.8	5.9 ± 2.0	6.3 ± 2.7
Education (≥college)†	36.7%	41.9%	29.0%
Fathers			
Age	35.5 ± 5.0	34.4 ± 5.1	33.6 ± 6.3
BMI (kg/m^2)	26.6 ± 3.1	27.4 ± 3.5	27.9 ± 3.9
Activity (Caltrac)	6.4 ± 1.4	6.2 ± 2.4	6.5 ± 1.8
Education (≥college)†	40.0%	54.8%	32.3%

SD, standard deviation; SF, skinfold.

* The term 3 to 6 years of age includes children from 3 years of age up to but not including 6 years of age.

† Proportion (column percentage) in each tertile having at least a college education.

Statistical Analysis

We calculated each child's mean daily servings of dairy products in early childhood by taking the average of all servings per day from all days of diet records collected before 6 years of age. Because the children ranged from 3.0 through 5.9 years of age at entry into the study, more diet records were available for some children than for others. The median number of days of diet records completed for the children before age 6 was 15 (range, 2 to 24 days of records).

We chose to use early childhood intake as our exposure variable for several reasons: dietary intake in children has been shown to track over time (37,38); within this study, there was strong tracking of dairy intake over time (e.g., 84% of children at 6 to 9 years of age had dairy intakes that were within 1 quintile of their reported intakes at 3 to 6 years of age; 81% were within 1 quintile through age 12); the large number of diet records collected before age 6 gives us very precise estimates of intake; parental report of intake for very young children is less likely to be biased by the child's existing level of body fat; and the reported intake precedes the determination of the anthropometry outcomes. As is generally the case, compliance with the completion of diet records diminished over time. Because there were more missing values at later ages, we avoided estimating average intake (from 3 to 12 years). Therefore, restricting the exposure period to early childhood provides both an unbiased estimate of intake and enables us to classify the children more accurately, thus maximizing our ability to detect between-group differences.

Change in body fat was estimated by calculating a slope for each anthropometry outcome (BMI and four SFs) for each child. We initially calculated two separate slopes for each measure for each child: slope from ages 3 to 13 years of age and from 5 to 13 years of age. Although the effect estimates were very similar for both slopes, we present the results here using the latter slopes for two reasons. First, body fat generally declines during the preschool years (during the period of adiposity rebound) before increasing in a more linear fashion into adolescence. Thus, the slopes estimated using age 5 as the anchor point more closely follow the assumptions of linearity. In addition, because children entered the study at different ages, the use of age 5 as a start point ensures that the slope for each child begins at the same age. Mean body fat in early adolescence was estimated as the mean of all available measures taken between 10 and 13 years of age.

Table 2. Child's nutrient intake according to sex-specific tertile of dairy intake

Energy-adjusted nutrient intakes (age 3 to 6 years)	Sex-specific tertile of dairy intake at 3 to 6 years of age		
	Tertile 1 ($n = 30$) (mean ± SD)	Tertile 2 ($n = 31$) (mean ± SD)	Tertile 3 ($n = 31$) (mean ± SD)
Total energy	1464 ± 164	1519 ± 222	1723 ± 330
Calories from fat (%)	32.2 ± 5.0	34.4 ± 4.0	34.1 ± 3.8
Calories from saturated fat (%)	12.0 ± 2.6	13.2 ± 1.8	13.7 ± 1.9
Calories from carbohydrates (%)	56.7 ± 5.9	53.8 ± 4.7	53.3 ± 4.2
Calories from protein (%)	12.7 ± 1.8	13.4 ± 1.4	14.2 ± 1.4
Fiber (grams)/1000 kcal	6.7 ± 1.2	6.5 ± 1.8	6.2 ± 1.1
Calcium (mg)/1000 kcal	399.1 ± 73.6	499.1 ± 66.3	585.8 ± 83.5
Magnesium (mg)/1000 kcal	117.7 ± 19.0	124.4 ± 19.6	133.0 ± 18.1
Vitamin A (μg RE)/1000 kcal	408.0 ± 145.3	465.3 ± 144.3	463.6 ± 136.8
Vitamin D (μg)/1000 kcal	2.5 ± 0.8	3.4 ± 0.8	4.3 ± 0.8
Fruit and vegetables/1000 kcal (servings)	2.5 ± 1.0	2.1 ± 0.8	2.1 ± 0.6
Whole grains/1000 kcal (servings)	0.3 ± 0.2	0.4 ± 0.2	0.4 ± 0.2
Sugar-sweetened beverages/1000 kcal (cups)	0.5 ± 0.3	0.4 ± 0.3	0.3 ± 0.3

SD, standard deviation; RE, retinol equivalents.

We divided the distribution of early childhood dairy intake into tertiles, separately for girls and boys. We then used ANOVA and analysis of covariance to estimate the crude and adjusted mean changes in body fat throughout childhood, as well as the mean levels of early adolescent body fat. Tests of statistical significance comparing anthropometry means in the highest and lowest tertiles of dairy intake used a standard Student's *t* test approach. Potential confounding was assessed by comparing the crude and adjusted mean anthropometry outcomes after controlling for the potential confounders described above. We retained the following variables that were found to confound the results to some degree in the final models: age, physical activity, baseline anthropometry, maternal education, energy intake per day, and percentage of calories from saturated fat. Models including hours of television viewing and intakes of fiber, whole grains, fruits and vegetables, and sugar-sweetened beverages yielded adjusted mean estimates that were generally within one decimal of the simpler models and no attenuation of the effects. Finally, we explored the inclusion of maternal BMI in a subanalysis.

Results

We began by examining the sex-specific dairy intakes per day at 3 to 6 years of age and found that girls had a median intake of 1.09, 1.59, and 2.01 servings of dairy per day in the lowest to highest intake tertile, respectively, whereas boys consumed 1.38, 2.03, and 2.84 servings per day. The cut-off points for defining the lower and upper tertiles of dairy intake in this study for girls were 1.25 and 1.85 servings per day; for boys, the cut-off points were 1.70 and 2.35 servings per day.

The characteristics of the children and their parents at baseline within each sex-specific tertile of dairy intake are shown in Table 1. At baseline, the child's sum of four SFs increased with increasing tertile of dairy intake. Physical activity levels were slightly higher for those with higher dairy intakes. Parental education levels were lowest in the highest dairy intake group. Fathers had slightly higher crude BMIs in the upper 2 tertiles of dairy intake than in the lowest tertile. Otherwise, there were few differences at baseline. None of these baseline differences were statistically significant at the level of $p = 0.05$.

There are noticeable differences in nutrient intakes at baseline associated with increasing dairy consumption per day (Table 2). Total energy increased in a linear fashion as dairy intake increased. The children with the lowest dairy intakes consumed proportionately fewer of their total calories as fat, saturated fat, and protein and more as carbohydrates. Differences in micronutrient intakes were as expected. With the exception of fiber, whole grains, and sugar-sweetened beverages, the intakes of all dietary variables in the highest tertile of dairy (and generally in the

Table 3. Effects of preschool dairy intake on slope of anthropometry from preschool to early adolescence

Dairy servings per day (3 to 6 years of age)	*N*	Mean anthropometry slopes, age 5 to 13 years					
		BMI	Triceps	Subscapular	Suprailiac	Abdominal	Sum of four SFs
Unadjusted models (mean ± SD)							
Dairy (sex-specific tertile)							
Tertile 1	30	0.77 ± 0.53	1.23 ± 0.88	1.26 ± 1.18	2.45 ± 1.71	2.19 ± 1.47	7.13 ± 4.74
Tertile 2	31	0.52 ± 0.52	0.97 ± 0.90	0.93 ± 1.19	1.85 ± 1.84	1.69 ± 1.89	5.47 ± 5.68
Tertile 3	31	0.65 ± 0.42	1.25 ± 1.04	1.09 ± 1.19	2.31 ± 1.79	1.95 ± 1.57	6.58 ± 5.28
Adjusted for age, activity, mother's education, and baseline anthropometry (mean ± SE)							
Dairy (sex-specific tertile)							
Tertile 1	30	0.77 ± 0.09	1.26 ± 0.17	1.32 ± 0.22	2.59 ± 0.33	2.47 ± 0.30	7.71 ± 0.94
Tertile 2	31	0.54 ± 0.09	1.01 ± 0.17	0.96 ± 0.22	1.81 ± 0.32	1.62 ± 0.29	5.54 ± 0.92
Tertile 3	31	0.64 ± 0.09	1.19 ± 0.17	0.99 ± 0.22	2.20 ± 0.32	1.75 ± 0.29	5.95 ± 0.92
*p**		0.312	0.768	0.308	0.401	0.088	0.193
Adjusted for age, activity, mother's education, baseline anthropometry, energy intake and percentage of energy from saturated fat (mean ± SE)							
Dairy (sex-specific tertile)							
Tertile 1	30	0.83 ± 0.09	1.40 ± 0.18	1.53 ± 0.23	2.97 ± 0.33	2.85 ± 0.29	8.82 ± 0.93
Tertile 2	31	0.52 ± 0.09	0.97 ± 0.16	0.94 ± 0.21	1.78 ± 0.31	1.60 ± 0.27	5.46 ± 0.87
Tertile 3	31	0.59 ± 0.09	1.09 ± 0.18	0.81 ± 0.23	1.86 ± 0.33	1.40 ± 0.29	4.94 ± 0.94
*p**		0.083	0.242	0.043	0.030	0.002	0.008

SF, skinfold; SD, standard deviation; SE, standard error.

* Comparison of group 1 vs. group 3.

middle tertile as well) were significantly different from those in the lowest tertile. Low dairy intakes were also associated with slightly higher intakes of fruits and vegetables and higher intakes of sugar-sweetened beverages.

Table 3 shows the effect of dairy consumption on the anthropometry slopes from ages 5 to 13 years. The crude mean anthropometry values were lowest in the middle tertile and highest in the lowest tertile of dairy intake. After adjusting for age, physical activity, the mother's education level, and baseline sum of four SFs, the results were similar, although the adverse effect of low dairy intake was slightly stronger after further adjustment for energy intake and percentage of calories from saturated fat. The slope of the child's sum of four SFs was still highest in the lowest tertile of dairy intake (slopes, 8.82, 5.46, and 4.94 mm change per year in the low to high tertiles of intake, respectively). When maternal BMI was added to the multivariable model (data not shown), the sums of four SFs were 8.5, 5.5, and 5.2 mm, respectively, in the lowest to highest dairy intake tertiles. Thus, addition of maternal adiposity to the model slightly attenuated the effect of dairy intake.

In the fully adjusted model in Table 4, we show that at 10 to 13 years of age, those children in the lowest tertile of dairy intake at baseline had a sum of four SFs of 82.4 mm, whereas those in each of the upper 2 tertiles had a sum of SFs that was ~25 mm lower. The results for BMI and the four individual SFs in Table 4 also suggest that dairy may have a threshold effect on adiposity. Based on these results, girls consuming <1.25 servings of dairy per day and boys consuming <1.70 servings per day in early childhood were at much higher risk for gaining excessive amounts of body fat by the time of early adolescence.

This possible threshold effect is further demonstrated in Table 5, showing the adjusted mean differences in the sum of four SFs according to dairy intake. Children in either of the upper two sex-specific tertiles of dairy intake had a slope of the sum of four SFs that was more than 3 mm lower than that of children in the lowest tertile. We also added both calcium and magnesium separately to the multivariable models. This was designed to explore whether controlling for these minerals might explain the protective effect of higher dairy intakes. However, there is no evidence that either calcium or magnesium explains the beneficial effects of dairy.

Discussion

This study supports the hypothesis that low intakes of dairy products in early childhood may promote the acqui-

Table 4. Effects of preschool dairy intake on anthropometry level in early adolescence

Dairy servings per day (3 to 6 years of age)	*N*	Mean anthropometry measures, ages 10 to 13 years					
		BMI	Triceps	Subscapular	Suprailiac	Abdominal	Sum of four SFs
Unadjusted models (mean ± SD)							
Dairy (sex-specific tertile)							
Tertile 1	30	20.9 ± 3.8	19.4 ± 6.4	13.4 ± 7.8	20.4 ± 11.0	20.0 ± 10.3	73.2 ± 32.4
Tertile 2	30	18.6 ± 3.4	16.0 ± 6.2	10.4 ± 7.0	15.1 ± 10.3	15.8 ± 11.2	57.6 ± 33.9
Tertile 3	30	19.7 ± 3.0	17.9 ± 6.5	12.2 ± 7.4	18.6 ± 10.6	18.0 ± 10.4	66.7 ± 32.7
Adjusted for age, activity, mother's education and baseline anthropometry (mean ± SE)							
Dairy (sex-specific tertile)							
Tertile 1	30	20.73 ± 0.57	19.25 ± 1.03	13.73 ± 1.36	21.35 ± 1.92	21.95 ± 1.81	76.76 ± 5.64
Tertile 2	30	18.84 ± 0.56	16.70 ± 1.02	10.81 ± 1.34	15.02 ± 1.89	15.42 ± 1.76	58.74 ± 5.53
Tertile 3	30	19.62 ± 0.56	17.33 ± 1.03	11.46 ± 1.38	17.78 ± 1.91	16.47 ± 1.79	61.98 ± 5.64
*p**		0.174	0.194	0.258	0.198	0.039	0.073
Adjusted for age, activity, mother's education, baseline anthropometry, energy intake, and percentage of energy from saturated fat (mean ± SE)							
Dairy (sex-specific tertile)							
Tertile 1	30	21.1 ± 0.6	20.2 ± 1.1	14.6 ± 1.4	23.2 ± 2.0	23.9 ± 1.8	82.4 ± 5.8
Tertile 2	30	18.8 ± 0.6	16.4 ± 1.0	10.6 ± 1.3	14.8 ± 1.9	15.2 ± 1.7	57.9 ± 5.4
Tertile 3	30	19.3 ± 0.6	16.7 ± 1.1	10.8 ± 1.5	16.1 ± 2.0	14.8 ± 1.8	57.2 ± 5.8
*p**		0.046	0.032	0.084	0.021	0.002	0.005

SF, skinfold; SD, standard deviation; SE, standard error.

* Comparison of group 1 vs. group 3.

sition of excess body fat over time. Girls in the lowest tertile of intake consumed <1.25 servings of dairy per day and boys <1.70 servings per day, intake levels that are below the recommended two servings per day for 3- to 6-year-old children. Children in the lowest tertile of dairy intake at that age gained an extra 25 mm of subcutaneous fat (in four SFs) by the time of early adolescence.

Children in the highest tertile of dairy intake had higher intakes of calories, fat, and saturated fat (and higher intakes of a number of beneficial nutrients). After adjusting for both energy and saturated fat, children in the highest dairy intake group generally had the lowest anthropometry measurements. When these two factors are dropped from the multivariable model, children in the higher dairy intake tertile had body fat levels that were higher than those in the middle tertile but consistently lower than those of children with the lowest dairy intakes. These results suggest that low levels of dairy intake should be avoided and that higher intake levels may be more beneficial when they are not accompanied by excessively high intakes of calories and fat. It is important to note that the levels of intake in this study are derived from all sources of dairy, including those from composite foods. The distribution of intake in this relatively small study does not allow us to evaluate fully possible adverse effects of very high levels of intake.

Dairy products may be consumed in high- and low-fat forms. We carried out a subanalysis to explore effects of consuming predominantly high-fat vs. reduced-fat forms of dairy. In that analysis, we classified children into four roughly equal groups of intake as follows: consumed ≥1.75 servings per day of predominantly low-fat dairy (i.e., >50% of dairy was of a reduced-fat form), consumed ≥1.75 servings per day of predominantly high-fat dairy, consumed <1.75 servings per day of predominantly low-fat dairy, and consumed <1.75 servings per day of predominantly high-fat dairy. After adjusting for child's age, sex, physical activity, energy intake, and baseline anthropometry and mother's education and baseline BMI, the adjusted mean sums of four SFs in early adolescence were 57.2, 64.6, 71.4, and 71.2 mm, respectively. For all anthropometry outcomes, adolescent body fat was lowest for those consuming ≥1.75 servings per day of reduced-fat dairy.

There are a number of clinical and laboratory investigations exploring possible mechanisms by which dairy consumption may lead to reduced levels of body fat. The calcium content of dairy has been a leading hypothesis.

Table 5. Adjusted mean differences in sum of four SFs according to dairy intake

Dairy servings per day (3 to 6 years of age)	Mean differences in sum of four SFs: Slope: age 5 to 13 years [mean (95% CI)]	Mean differences in sum of four SFs: Mean SFs: age 10 to 13 years [mean (95% CI)]
Dairy (sex-specific tertile): unadjusted model		
Tertile 1*	-	-
Tertile 2	−1.66 (−4.27, −0.95)	−15.62 (−32.04, 0.80)
Tertile 3	−0.55 (−3.14, −2.04)	−6.55 (−22.97, 9.87)
Dairy (sex-specific tertile): adjusted model†		
Tertile 1*	-	-
Tertile 2	−3.36 (−5.73, −0.98)	−24.54 (−39.23, −9.86)
Tertile 3	−3.88 (−6.53, −1.23)	−25.16 (−41.54, −8.79)
Dairy (sex-specific tertile): adding dietary calcium (mg) to the adjusted model		
Tertile 1*	-	-
Tertile 2	−4.20 (−6.83, −1.57)	−29.14 (−45.32, −12.96)
Tertile 3	−5.89 (−9.76, −2.03)	−36.55 (−60.43, −12.67)
Dairy (sex-specific tertile): adding dietary magnesium (mg) to the adjusted model		
Tertile 1*	-	-
Tertile 2	−3.29 (−5.67, −0.90)	−23.14 (−37.82, −8.45)
Tertile 3	−3.63 (−6.47, −0.79)	−21.18 (−38.42, −3.93)

SF, skinfold; CI, confidence interval.

* Reference category.

† Adjusted for age, activity, energy intake, percentage of calories from saturated fat, mother's education, and baseline anthropometry.

From the earliest epidemiologic observations (9) to the more recent animal studies (39,40), there is support for the importance of this mineral in regulating body fat storage. Our results, however, provide no support for the hypothesis that calcium is responsible for the protective effect of dairy intake. When we added calcium to the multivariable models, there was no attenuation of the dairy effects. In fact, the effects were strengthened. Because calcium intake in these models reflects total dietary calcium, not just calcium from dairy sources, it may be that both total calcium and total dairy exert independent beneficial effects on body fat change. It could also be that some of the apparent protective effect of calcium found in earlier studies is largely or partially attributable to something else in dairy foods.

There are a number of other bioactive compounds in dairy that may be involved in weight regulation and/or glucose metabolism. Dairy products have high concentrations of branched-chain amino acids, and one essential protein amino acid (leucine) may play an important role in the partitioning of dietary energy. In a recent review of the evidence on leucine, Layman (41) suggests that isocaloric substitution of protein (containing leucine) for carbohydrate promotes fat loss while preserving lean body mass.

Other compounds such as conjugated linoleic acid (CLA) should be examined further, although recent evidence suggests that it is unlikely that CLA explains the dairy/body fat association because the CLA isomer found in dairy products differs from the isomer in supplements that has been shown to affect body weight and composition (42). Because magnesium may play a role in obesity-related insulin resistance, it is possible that the magnesium content of dairy products may affect weight regulation as well (43). However, controlling for magnesium in our analyses led to very little attenuation of the dairy effects.

There are some limitations of the current study, but the most apparent is its sample size. The Framingham Children's Study is a small study, and although the families were followed intensively, our ability to stratify the data by factors such as gender or other lifestyle or dietary factors is very limited. This limitation is balanced, in part, by the wealth of the data for individual children. For children under 6 years of age, we had an average of 15 days of diet records per child that we used to estimate mean dairy intake. The large number of diet records provides substantial precision around the estimated effects of dairy intake on body fat. This is an important strength of the study.

For this manuscript, we carried out a prospective analysis rather than examining repeated sets of concurrently collected diet record and anthropometry data because the latter analyses would be more subject to reporting bias and confounding by indication. For example, if a parent restricted an overweight child's dairy intake, then low dairy intake might be falsely linked with overweight. Because dietary intake tracks over time, children consuming low levels of dairy before age 6 will be more likely to consume low levels of dairy at 6 to 9 years of age. It is not plausible that the adverse effect of low preschool dairy intake could be explained by reversal of intake patterns during subsequent age periods.

Another important strength of the study relates to the repeated measures of anthropometry both within and across visits throughout childhood. This enabled us to examine the effects of dietary intake on the change in the child's level of body fat. The strict measurement protocols and replicate measures of anthropometry also serve to enhance the precision of the estimated effects of dairy intake.

Dairy is an important source of many nutrients for growing children. This study provides evidence to support the hypothesis that young children who fail to meet the recommended guidelines for dairy intake may have an added risk of gaining excess body fat.

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References

1. **Kuczmarski RJ, Flegal KM, Campbell SM, Johnson CL.** Increasing prevalence of overweight among US adults: The National Health and Nutrition Examination Surveys, 1960 to 1991. *JAMA.* 1994;272:205–11.
2. **Flegal KM, Carroll MD, Kuczmarski RJ, Johnson CL.** Overweight and obesity in the United States: prevalence and trends, 1960–1994. *Int J Obes Relat Metab Disord.* 1998;22:39–47.
3. **Troiano RP, Flegal KM, Kuczmarski RJ, Campbell SM, Johnson CL.** Overweight prevalence and trends for children and adolescents: The National Health and Nutrition Examination Surveys, 1963 to 1991. *Arch Pediatr Adolesc Med.* 1995;149:1085–91.
4. **Flegal KM, Carroll MD, Ogden CL, Johnson CL.** Prevalence and trends in obesity among US adults, 1999–2000. *JAMA.* 2002;288:1723–7.
5. **Hedley AA, Ogden CL, Johnson CL, Carroll MD, Curtin LR, Flegal KM.** Prevalence of overweight and obesity among US children, adolescents, and adults, 1999–2002. *JAMA.* 2004;291:2847–50.
6. **Guo SS, Wu W, Chumlea WC, Roche AF.** Predicting overweight and obesity in adulthood from body mass index values in childhood and adolescence. *Am J Clin Nutr.* 2002;76:653–8.
7. **Freedman DS, Khan LK, Dietz WH, Srinivasan SR, Berenson GS.** Relationship of childhood obesity to coronary heart disease risk factors in adulthood: the Bogalusa Heart Study. *Pediatrics.* 2001;108:712–8.
8. **Steinberger J, Moran A, Hong C-P, Jacob DR, Sinaiko AR.** Adiposity in childhood predicts obesity and insulin resistance in young adulthood. *J Pediatr.* 2001;138:469–73.
9. **McCarron DA, Morris CD, Henry HJ, Stanton JL.** Blood pressure and nutrient intake in the United States. *Science.* 1984;224:1392–8.
10. **Zemel MB, Shi H, Greer B, et al.** Regulation of adiposity by dietary calcium. *FASEB J.* 2000;14:1132–8.
11. **Kim JH, Kiefer LL, Woychik RP, et al.** Agouti regulation of intracellular calcium: role of melanocortin receptors. *Am J Physiol.* 1997;272:E379–84.
12. **Zemel MB, Kim JH, Woychik RP, et al.** Agouti regulation of intracellular calcium: role in the insulin resistance of viable yellow mice. *Proc Natl Acad Sci U S A.* 1995;92:4733–7.
13. **Heaney RP.** Normalizing calcium intake: projected population effects for body weight. *J Nutr.* 2003;133:268–70S.
14. **Teegarden D.** Calcium intake and reduction in weight or fat mass. *J Nutr.* 2003;133:249–51S.
15. **Parikh SJ, Yanovski JA.** Calcium intake and adiposity. *Am J Clin Nutr.* 2003;77:281–7.
16. **Barr SI.** Increased dairy product or calcium intake: is body weight or composition affected in humans? *J Nutr.* 2002;133:245–8S.
17. **Zemel MB, Richards J, Mathis S, Milstead A, Gebhardt L, Silva E.** Dairy augmentation of total and central fat loss in obese subjects. *Int J Obes Relat Metab Disord.* 2005;29:391–7.
18. **Zemel MB, Thompson W, Milstead A, Morris K, Campbell P.** Calcium and dairy acceleration of weight and fat loss during energy restriction in obese adults. *Obes Res.* 2004;12:582–5.
19. **Summerbell CD, Watts C, Higgins JP, Garrow JS.** Randomised controlled trial of novel, simple, and well supervised weight reducing diets in outpatients. *BMJ.* 1998;317:1487–9.
20. **Garrow JS, Webster JD, Pearson M, Pacy PJ, Harpin G.** Inpatient-outpatient randomized comparison of Cambridge diet versus milk diet in 17 obese women over 24 weeks. *Int J Obes Relat Metab Disord.* 1989;13:521–9.
21. **Gunther CW, Legowski PA, Lyle RM, et al.** Dairy products do not lead to alterations in body weight and fat mass in young women in a one year intervention. *Am J Clin Nutr.* 2005;81:751–6.
22. **Bruening KS, Gilbride JA, Passannante MR, McClowry S.** Dietary intake and health outcomes among young children attending 2 urban day-care centers. *J Am Diet Assoc.* 1999;99:1529–35.
23. **Phillips SM, Bandina LG, Cyr H, Cloclough-Douglas S, Naumova E, Must A.** Dairy food consumption and body weight and fatness studied longitudinally over the adolescent period. *Int J Obes Relat Metab Disord.* 2003;27:1106–13.
24. **Cadogan J, Eastell R, Jones N, Barker ME.** Milk intake and bone mineral acquisition in adolescent girls: randomised, controlled intervention trial. *BMJ.* 1997;315:1255–60.

25. **Chan GM, Hoffman K, McMurry M.** Effects of dairy products on bone and body composition in pubertal girls. *J Pediatr.* 1995;126:551–6.
26. **Fisher JO, Mitchell DC, Smiciklas-Wright H, Mannino ML, Birch LL.** Meeting calcium recommendations during middle childhood reflects mother-daughter beverage choices and predicts bone mineral status. *Am J Clin Nutr.* 2004;79:698–706.
27. **Barba G, Troiano E, Russo P, Venezia A, Siani A.** Inverse association between body mass and frequency of milk consumption in children. *Br J Nutr.* 2005;93:15–9.
28. **Carruth BR, Skinner JD.** The role of dietary calcium and other nutrients in moderating body fat in preschool children. *Int J Obes Relat Metab Disord.* 2001;25:559–66.
29. **Skinner JD, Bounds W, Carruth BR, Ziegler P.** Longitudinal calcium intake is negatively related to children's body fat indexes. *J Am Diet Assoc.* 2003;103:1626–31.
30. **Novotny R, Daida YG, Acharya S, et al.** Dairy intake is associated with lower body fat and soda intake with greater weight in adolescent girls. *J Nutr.* 2004;134:1905–9.
31. **Huang T T-K, McCrory MA.** Dairy intake, obesity, and metabolic health in children and adolescents: knowledge and gaps. *Nutr Rev.* 2005;63:71–80.
32. **Balogun JA, Martin DA, Clendenin MA.** Calorimetric validation of the Caltrac accelerometer during level walking. *Phys Ther.* 1989;69:501–9.
33. **Sallis JF, Buono MJ, Roby JJ, et al.** The Caltrac accelerometer as a physical activity monitor for school-age children. *Med Sci Sports Exerc.* 1990;22:698–703.
34. **Schakel SF, Sievert YA, Buzzard IM.** Sources of data for developing and maintaining a nutrient data base. *J Am Diet Assoc.* 1988;88:1268–71.
35. **U.S. Department of Agriculture Health Inspection Service.** *The Food Guide Pyramid: Home and Garden Bulletin Number 252.* Washington, DC: U.S. Government Printing Office; 1992.
36. **U.S. Department of Agriculture.** *Food and Nutrient Intakes by Individuals in the United States, 1 Day, 1989–1991, NFS Report No. 91–92.* Washington, DC: U.S. Government Printing Office; 1995.
37. **Singer MR, Moore LL, Garrahie EJ, Ellison RC.** The tracking of nutrient intake in young children: The Framingham Children's Study. *Am J Public Health.* 1995;85:1673–7.
38. **Boulton TJ, Magarey AM, Cockington RA.** Tracking of serum lipids and dietary energy, fat, and calcium intake 1 to 15 years. *Acta Paediatr.* 1995;84:1050–5.
39. **Zemel MB.** Regulation of adiposity and obesity risk by dietary calcium: mechanisms and implications. *Am J Clin Nutr.* 2002;21:146–51S.
40. **Sun X, Zemel MB.** Calcium and dairy products inhibit weight and fat regain during ad libitum consumption following energy restriction in Ap2-agouti transgenic mice. *J Nutr.* 2004;134:3054–60.
41. **Layman DK.** The role of leucine in weight loss diets and glucose homeostasis. *J Nutr.* 2002;133:261–7S.
42. **Belury MA, Mahon A, Banni S.** The conjugated linoleic acid (CLA) isomer, t10c12-CLA, is inversely associated with changes in body weight and serum leptin in subjects with type 2 diabetes mellitus. *J Nutr.* 2002;133:257–60S.
43. **Paolisso G, Barbagallo M.** Hypertension, diabetes mellitus, and insulin resistance: the role of intracellular magnesium. *Am J Hypertens.* 1997;10:346–55.