Journal of Public Health | Vol. 41, No. 2, pp. 338–345 | doi:10.1093/pubmed/fdy064 | Advance Access Publication April 5, 2018

Association of dairy intake with weight change in adolescents undergoing obesity treatment

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ABSTRACT

Background The role of dairy products in obesity treatment for adolescents is unclear. The study purpose was to assess the association between dairy intake and changes in BMI *z*-score (*z*BMI) during adolescent obesity treatment.

Methods Observational study nested within a randomized control trial. Linear mixed-effects regression models were adjusted for important non-lifestyle factors then further adjusted for dietary and physical activity variables. In total, 91 adolescents were studied.

Results Each serving of total dairy ($\beta = -0.0054$, $P < 0.01$), unflavored milk ($\beta = -0.012$, $P < 0.01$), reduced fat ($\beta = -0.0078$, $P < 0.05$), and low fat/fat-free products ($\beta = -0.0149$, $P < 0.01$) was associated with a decrease in zBMI over 12 months. These associations were no longer significant after adjustment for other dietary and physical activity factors. Sugar-sweetened beverage intake was inversely associated with intake of total dairy ($\beta = -0.186$, $P = 0.001$), unflavored milk ($\beta = -0.115$, $P = 0.003$) and low fat/fat-free dairy ($\beta = -0.125$, $P = 0.001$).

Conclusions Intakes of total dairy, unflavored milk, reduced fat dairy and low fat/fat-free dairy products are associated with improved obesity treatment outcomes among adolescents. This could be due to co-occurring healthy lifestyle behaviors or to replacement of other food and beverages associated with obesity, such as sugar-sweetened beverages, by dairy products.

Keywords obesity, children, food and nutrition

Background

Nearly one third of US children and adolescents aged 2–19 years are overweight or obese.[1] There has been an increasing interest in the role of dairy consumption in obesity prevention. Data from cross-sectional studies in children and adolescents support a beneficial or neutral effect of dairy product consumption on body weight or body fat.[2–9] Results from longitudinal studies have been mixed, with some studies showing an inverse association of dairy consumption with overweight and obesity[4,10–12] while other research found no association.[13–17] One study reported a positive association between dairy consumption and weight gain in adolescents, but this finding was not confirmed after adjustment for energy intake.[18] Studies examining associations between dairy intake and body weight in children and adolescents generally do not assess results by type of dairy product or dairy fat levels. Furthermore, results from observational studies of primarily non-obese and untreated subjects may not be generalizable to children and adolescents undergoing obesity treatment.

A central component of behavioral approaches to childhood obesity is modification of dietary intake. In addition to water, whole grain, fruit and vegetable intake, milk and other low-fat dairy intake are positively reinforced in most approaches to behavioral obesity treatment. Some adult studies have shown that overweight or obese individuals who are on a reduced calorie diet experience greater body weight and fat loss when

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consuming dairy products and/or calcium.[19–22] There is however no known research specifically investigating dairy intake and weight change for children and adolescents participating in obesity treatment interventions.

The aim of this study was to assess the interaction of dairy consumption by time, as a proportion of total energy intake, on change in BMI *z*-score, using a nested observational study design with a secondary analysis of existing data from a randomized controlled trial (RCT) of obesity treatment. A secondary aim was to assess whether these associations differ between different types of dairy products.

Methods

Design and subjects

This was an observational study (cross-sectional and cohort study designs) nested within a RCT and using existing data from 'Mind Your Body', a RCT designed to investigate the impact of obesity treatment on bone health among 91 obese adolescents.[23,24] Inclusion criteria were age ≥10 and <15 years and a BMI ≥ 97th percentile for age and sex. Participants were excluded if they had a BMI *z*-score greater than +3.00 SD to avoid severe co-morbidities. Additional exclusion criteria included syndromic or secondary obesity, psychosis, eating disorders, orthopedic problems interfering with physical activity, weight loss medications, cigarette smoking and any other medications or chronic conditions that could interfere with the intervention.

Interventions and procedures

In short, participants randomized to the behavioral intervention met weekly for 18 weeks, then every other week from weeks 20 to 28, and once a month thereafter through week 52. Adolescents and parents received manuals that provided lessons and homework assignments for each meeting.[25,26] Self-monitoring diaries were also provided for adolescents to record their calories, physical activity and sedentary behaviors. At each session, participants submitted their self-monitoring diaries to their assigned health coach. Children and parents met separately during each behavioral session for an hour. Subjects randomized to usual care met with a registered dietician nine times during the 1-year period. They received general dietary recommendations for weight loss, but no theory-based behavior modification intervention.

Study measurements took place at baseline, 3, 6 and 12 months at The Children's Hospital of Philadelphia (CHOP) General Clinical Research Center (GCRC). Each adolescent's weight (0.1 kg) was measured on a digital electronic scale (Seca, Munich, Germany), and stature (0.1 cm) on a stadiometer (Holtain, Crymych, UK) by trained research staff. All measurements were taken and recorded in triplicate and the mean used in analyses. BMI was calculated as weight (kg)/height^2 (m^2) and converted into a *z*-score using the US reference population.[27] Each subject completed a 3-day dietary recall at baseline, 6 and 12 months, performed by GCRC bionutritionists using telephone interviews. The recalls took place on three separate days randomly selected by the bionutritionists, including 2 week days and one weekend day using the Nutrition Data System program (University of Minnesota) that includes prompts for questions depending on the food item entered as part of the interview.[28] The database contains over 16 000 food items, and is continually updated to reflect changes in the marketplace. Physical activity was measured using an ActiGraph GT1M accelerometer (ActiGraph, LLC, Fort Walton Beach, FL) worn on the right side attached to a waist belt at baseline and 6 months. Subjects were instructed to wear the device during waking hours for seven days (including 2 weekend days), and to record each time the device was removed and replaced. The average number of activity counts per minute as well as the percentage of time spent in sedentary activity, determined using validated activity thresholds,[29] were included as covariates in the analyses.

Data analysis

The unit of measure of dairy consumption was reported as servings per day. A serving of dairy beverage was defined as 8 ounces. Data were analyzed separately as servings of total dairy, milk, yogurt and cheese. Separate analyses were also conducted based on amount of dairy fat (fat free, reduced fat, full fat) in the consumed dairy products. There were a total of 250 3-day dietary interviews completed with obese subjects over the study period (87 at baseline, 84 at 6 months and 79 at 12 months).

Prior to formal hypotheses testing, descriptive analyses were conducted to characterize the study sample. This consisted of frequencies for categorical variables (such as race or sex), and means and 95% confidence intervals for continuous variables. Linear mixed effects regression models with random intercepts were used to assess the effects of dairy intake on BMI *z*-score change. Mixed effects models provide a useful approach to accounting for interdependence in multiple observations within individuals.[30–32] Mixed effects models assume that the data within clusters are dependent among the observations. These models allow for simultaneously estimating the parameters of the regression model and the variance components that account for the data clustering.[30] Further, mixed-effects regression models use all the data that are available, as these models do not delete participants with missing data and can analyze data obtained at different time points across studies. Mixed-effects regression models take into account serial correlation between repeated observations and changes in the variability over time, which is relevant because increases in variability for weight control over time are commonly observed in obesity treatment and prevention studies.[33]

For the primary aims of this study, energy-adjusted dairy intake was entered in the mixed effects regression models as a time variant predictor of BMI *z*-score, with subject effects entered as random and visit as timeline, measured in months. Race, baseline BMI *z*-score, baseline age, study and intervention conditions were entered as fixed effects; these variables were chosen a-prior as potential confounders to be included in the mixed effects models. Adjustment for total energy intake is important as the energy from dairy food, if consumed as an excess of the total daily energy, could mask any true effect of dairy on weight loss. This is particularly relevant for family-based behavioral obesity programs since children may not substitute other foods from their diet when increasing intake of dairy products, which would result in adding extra energy. For this reason all dairy and food group variables entered into the models were energy adjusted. Energy-adjusted variables were computed using the method described by Willett and Stampfer[34] as the residuals from the regression model with total caloric intake as the independent variable and the dairy/food group variable as the dependent variable. The dairy/food group residuals provide a measure of dairy intake independent of total energy intake.

The analytic plan for the specific aims involved a 3-tier approach. First, a single univariate regression model was used to examine the unadjusted association between energy-adjusted dairy intake and BMI *z*-score. The equation for this model was: BMI *z*-score = α + β1 (servings of total dairy per day) + β2 (total energy intake) + β3 (visit) + β4 (servings of total dairy per day $\times$ visit). Next, BMI *z*-score was regressed on dairy intake after adjustment for potential confounding variables chosen a priori: race, baseline BMI *z*-score, study visit, intervention condition, total energy intake, family income and parental education. The equation for the second model was: BMI *z*-score = α + β1 (servings of total dairy per day) + β2 (baseline BMI *z*-score) + β3 (total energy intake) + β4 (visit) + β5 (race) + β6 (family income) + β7 (maternal education) + β8 (paternal education) + β9 (intervention condition) + β10 (servings of total dairy per day $\times$ visit). Finally, variables added to the adjusted model included energy-adjusted fruits, vegetables, whole-grain breads, and sugar-sweetened beverages intakes, as well as physical activity and sedentary behavior. An interaction term for dairy intake $\times$ visit was added to the model during each analytic step to test the study hypothesis. The equation for the final model was: BMI *z*-score = α + β1 (servings of total dairy per day) + β2 (baseline BMI *z*-score) + β3 (total energy intake) + β4 (visit) + β5 (race) + β6 (family income) + β7 (maternal education) + β8 (paternal education) + β9 (fruit consumption) + β10 (vegetable consumption) + β11 (whole-grain bread consumption) + β12 (sugar-sweetened beverage intake) + β13 (physical activity) + β14 (sedentary behavior) + β15 (intervention condition) + β16 (servings of total dairy per day $\times$ visit).Unadjusted and adjusted beta coefficients and 95% confidence intervals for BMI *z*-score were calculated, and statistical significance was assessed by using a Wald's test. Multicollinearity was assessed using variance inflation factors, and model fit by computing Akaike Information Criterion values. We also computed post-hoc unadjusted mixed models in order to investigate whether increased dairy intake was associated with decreases in sugar-sweetened beverages. All analyses were repeated for the subgroup of dairy products (by type and by fat content). Lastly, all analyses were repeated using unadjusted BMI and unadjusted weight, as these have been suggested as better indicators of change over time for obese children and adolescents.[35] For these two outcomes, age and sex were also included as confounding variables in models 1, 2 and 3. All analyses were conducted using SAS 9.3 software with two-sided tests and alpha of 0.05 as the criterion for statistical significance.

Results

Subjects' characteristics are presented for baseline, 6 and 12 months in Table 1. The interaction of energy-adjusted total dairy intake by time was significantly associated with BMI *z*-score change in both simple ($P < 0.05$) and intermediate ($P < 0.01$) mixed-effects regression models (Table 2). The negative coefficients indicate that the greater the dairy intake, the more loss in BMI *z*-score over 12 months. These results were no longer significant after adjustment for other dietary factors and physical/sedentary activities.

The interaction of energy-adjusted unflavored milk by time was negatively associated with BMI *z*-score change through 12 months in both simple ($P < 0.01$) and intermediate ($P < 0.01$) mixed-effects regression models, but not in the model adjusted for other dietary factors and physical/sedentary activities. No statistically significant associations with BMI *z*-score change were found with the other types of dairy products (flavored milk, yogurt, cheese, cream and dairy dessert).

By level of dairy fat, the interaction of energy-adjusted reduced fat dairy by time ($P < 0.05$) and energy-adjusted low

Table 1 Characteristics of the adolescents undergoing a 12-month obesity treatment program (percentage or mean (95% confidence interval))

Anthropometric variables	*Baseline,* n = *91*	*6 Months,* n = *86*	*12 Months,* n = *83*
Race, %			
Black	62.6	61.6	62.7
White	33.0	33.7	32.5
Other	4.4	4.7	4.8
Sex, % female	64.8	67.4	65.1
Weight, kg	85.74 (82.14, 89.38)	87.13 (83.34, 90.91)	90.87 (87.12, 94.63)
BMI, kg/m^2	33.86 (32.84, 34.88)	33.51 (32.36, 34.65)	34.16 (33.00, 35.32)
*z*BMI, SD	2.39 (2.34, 2.43)	2.31 (2.25, 2.37)	2.30 (2.23, 2.37)
Dietary variables	*Baseline,* n = *87*	*6 Months,* n = *84*	*12 Months,* n = *79*
Total dairy servings/day	1.61 (1.43, 1.80)	1.45 (1.28, 1.62)	1.76 (1.56, 1.97)
Servings of unflavored milk/day	0.57 (0.45, 0.69)	0.65 (0.52, 0.78)	0.64 (0.52, 0.77)
Servings of flavored milk/day	0.15 (0.08, 0.21)	0.04 (0.02, 0.07)	0.12 (0.07, 0.17)
Servings of yogurt/day	0.04 (0.02, 0.07)	0.06 (0.03, 0.09)	0.07 (0.04, 0.11)
Servings of cheese/day	0.61 (0.52, 0.70)	0.53 (0.44, 0.61)	0.63 (0.51, 0.74)
Servings of cream/day	0.026 (0.006, 0.047)	0.023 (−0.004, 0.051)	0.048 (0.015, 0.081)
Servings of dairy dessert/day	0.21 (0.14, 0.29)	0.15 (0.07, 0.23)	0.26 (0.16, 0.35)
Servings of full fat dairy/day	0.44 (0.36, 0.53)	0.37 (0.30, 0.44)	0.42 (0.32, 0.52)
Servings of reduced fat dairy/day	0.61 (0.50, 0.72)	0.44 (0.36, 0.53)	0.52 (0.39, 0.66)
Servings of low fat or fat-free dairy/day	0.35 (0.24, 0.46)	0.48 (0.35, 0.62)	0.56 (0.43, 0.69)

fat/fat-free dairy ($P < 0.01$), but not energy-adjusted full fat were negatively associated with BMI *z*-score change through 12 months in both simple and intermediate mixed-effects regression models. Again, the model adjusted for other dietary factors and physical/sedentary activities did not show any statistically significant associations.

Multicollinearity was assessed using variance inflation factors (VIFs). Tests for multicollinearity for model 1 indicated a very low level of multicollinearity for all variables (VIF = 1.015 for dairy intake, VIF = 1.005 for energy intake and VIF = 1.013 for visit). For models 2 and 3, tests indicated a low to moderate level of multicollinearity associated with dairy intake (VIF = 1.754 in model 2 and VIF = 4.809 in model 3). For model 3, examination of VIFs as well as condition indices and variance proportions indicated that maternal and paternal education (VIF = 6.825 and VIF = 3.126, respectively), family income (VIF = 5.899) and race (VIF = 6.557) are associated, and thus model parameters for these confounding variables may not be well estimated and should be interpreted with caution.

Similar results, though not always statistically significant, were found for the secondary outcomes BMI and body weight (Table 2). The largest significant effect size on weight was observed for low fat/fat-free dairy intake: for each additional serving of low fat/fat-free dairy, subjects lost 0.45 kg (95% CI: 0.21–0.68, $P < 0.01$) over the 12-month period, ~1 pound, after adjustment for study arm and other important non-dietary, non-physical activity confounding factors. Our post-hoc examination of dairy intake with sweetened beverages indicated that sugar-sweetened beverages was inversely associated with intake of total dairy ($\beta = -0.186$, $P = 0.001$), unflavored milk ($\beta = -0.115$, $P = 0.003$) and low fat/fat free dairy ($\beta = -0.125$, $P = 0.001$). There were no other significant associations by dairy type or level of dairy fat with sugar-sweetened beverages.

Discussion

Main finding of this study

To our knowledge, this is the first longitudinal study to assess the association between different types of dairy intakes and success in a weight loss program among adolescents. The findings suggest that total dairy, unflavored milk, reduced fat and low fat/fat free dairy intakes are associated with greater decrease in BMI *z*-score after adjustment for important confounding factors, but no longer associated after adjustment for other dietary and physical activity patterns.

What is already known on this topic

Studies examining associations between dairy intake and body weight generally do not assess results by type of dairy

Table 2 Mixed-effects regression analysis testing the interaction of different types of dairy intake by time with changes in BMI *z*-score (zBMI), BMI and weight over a 12-month weight loss program[a]

	Beta estimate for dairy intake × visit (95% CI)			
	Model 1[b]	*Model 2*[b]	*Model 3*[b]	*AIC*[c] *Model 1/Model 2/Model 3*
Total dairy				
				AIC for total dairy models
zBMI, SD	−0.005 (−0.010, −0.001)*	−0.007 (−0.012, −0.003)**	−0.002 (−0.006, 0.003)	zBMI: −61.3/−133.9/−95.3
BMI, kg/m^2	−0.028 (−0.077, 0.021)	−0.057 (−0.108, −0.007)*	−0.005 (−0.057, 0.047)	BMI: 1191.8/837.0/390.2
Weight, kg	−0.133 (−0.281, 0.014)	−0.209 (−0.359, −0.059)**	−0.055 (−0.190, 0.079)	Weight: 1728.0/1275.5/573.1
By type of diary				
				AIC for type of dairy models
Unflavored milk				*z*BMI: −22.4/−93.2/−11.5
*z*BMI, SD	−0.0090 (−0.0156, −0.0025)**	−0.0120 (−0.0187, −0.0052)**	0.0044 (−0.0046, 0.0134)	BMI: 1187.5/835.1/395.1
BMI, kg/m^2	−0.079 (−0.154, −0.005)*	−0.101 (−0.175, −0.027)**	0.021 (−0.072, 0.113)	Weight: 1703.9/1252.3/546.8
Weight, kg	−0.228 (−0.451, −0.005)*	−0.299 (−0.518, −0.079)**	0.213 (−0.008, 0.434)	
Flavored milk				
*z*BMI, SD	0.0031 (−0.0118, 0.0180)	−0.0059 (−0.0219, 0.0100)	0.0095 (−0.0133, 0.0323)	
BMI, kg/m^2	0.050 (−0.120, 0.220)	−0.089 (−0.263, 0.085)	0.022 (−0.232, 0.276)	
Weight, kg	−0.144 (−0.652, 0.364)	−0.362 (−0.880, 0.156)	−0.021 (−0.626, 0.584)	
Yogurt				
*z*BMI, SD	0.0069 (−0.0243, 0.0381)	0.0184 (−0.0148, 0.0515)	−0.0208 (−0.0667, 0.0251)	
BMI, kg/m^2	0.115 (−0.237, 0.467)	0.200 (−0.160, 0.560)	−0.168 (−0.692, 0.357)	
Weight, kg	0.076 (−0.977, 1.13)	0.190 (−0.880, 1.261)	−1.46 (−2.71, −0.202)*	
Cheese				
*z*BMI, SD	−0.0055 (−0.0137, 0.0027)	−0.0070 (−0.0152, 0.0013)	−0.0030 (−0.0119, 0.0059)	
BMI, kg/m^2	−0.013 (−0.105, 0.079)	−0.041 (−0.130, 0.049)	0.017 (−0.083, 0.118)	
Weight, kg	−0.111 (−0.387, 0.165)	−0.204 (−0.471, 0.063)	−0.050 (−0.290, 0.191)	
Cream				
*z*BMI, SD	−0.0140 (−0.0532, 0.0251)	−0.0181 (−0.0629, 0.0266)	0.0073 (−0.0374, 0.0521)	
BMI, kg/m^2	0.054 (−0.389, 0.497)	−0.105 (−0.593, 0.383)	−0.047 (−0.532, 0.438)	
Weight, kg	0.417 (−0.911, 1.74)	0.144 (−1.31, 1.59)	0.414 (−0.739, 1.57)	
Dairy dessert				
*z*BMI, SD	0.0018 (−0.0083, 0.0118)	0.0019 (−0.0083, 0.0121)	−0.0017 (−0.0117, 0.0082)	
BMI, kg/m^2	0.021 (−0.092, 0.135)	0.029 (−0.082, 0.140)	−0.029 (−0.137, 0.000)	
Weight, kg	0.035 (−0.305, 0.375)	0.0390 (−0.291, 0.369)	−0.195 (−0.452, 0.062)	
By dairy fat content				
				AIC for dairy fat content models
Full fat				zBMI: −43.7/−120.9/−68.6
*z*BMI, SD	0.0006 (−0.0087, 0.0010)	−0.0025 (−0.0119, 0.0068)	−0.0010 (−0.0089, 0.0070)	BMI: 1195.3/839.2/398.3
BMI, kg/m^2	0.002 (−0.103, 0.108)	−0.042 (−0.145, 0.060)	0.005 (−0.087, 0.097)	Weight: 1718.4/1264.8/573.9
Weight, kg	0.095 (−0.214, 0.404)	−0.107 (−0.408, 0.194)	−0.110 (−0.348, 0.129)	
Reduced fat				
*z*BMI, SD	−0.0083 (−0.0157, −0.0010)*	−0.0078 (−0.0150, −0.0007)*	−0.0033 (−0.0113, 0.0048)	
BMI, kg/m^2	−0.057 (−0.140, 0.026)	−0.059 (−0.137, 0.019)	−0.012 (−0.105, 0.081)	
Weight, kg	−0.205 (−0.449, 0.038)	−0.195 (−0.424, 0.034)	0.037 (−0.205, 0.280)	
Low fat or fat free				
*z*BMI, SD	−0.0087 (−0.0152, −0.0022)**	−0.0149 (−0.0224, −0.0075)**	0.0005 (−0.0079, 0.0089)	
BMI, kg/m^2	−0.047 (−0.120, 0.027)	−0.113 (−0.195, −0.032)**	0.016 (−0.081, 0.112)	
Weight, kg	−0.286 (−0.502, −0.071)**	−0.445 (−0.683, −0.208)**	0.147 (−0.101, 0.395)	

*$P < 0.05$, **$P < 0.01$.

[a]Beta estimates and 95% CIs were computed using multivariate mixed-effects regression analyses. Separate analyses were conducted for each dependent variable of *z*BMI, BMI and weight. All dairy variables reported and food groups included in the models are energy-adjusted.

[b]Model 1 is adjusted for total energy intake. Model 2 is additionally adjusted for family income, parental education, race, baseline *z*BMI/BMI/weight and study condition. For BMI/weight, age and sex are also included. Model 3 is additionally adjusted for physical activity, screen time and energy-adjusted intake of fruit, vegetable, whole grains and sugar.

[c]AIC = Akaike Information Criterion. The lower the value, the better the model fit.

product or amount of dairy fat consumed. One exception is a recent study, examining data from NHANES, 2005–8, that found that dairy intake and yogurt consumption were each independently associated with lower body fat in children based on subscapular skinfold measurement.[36] Limited research in adults show the beneficial effects of dairy products such as yogurt and cheese,[37–39] and suggest that type of dairy product could exert effects on weight loss through unique mechanisms and independent of calcium intake. Specific types of dairy products could have different effects on metabolic traits[40,41] due to differences in absorbability that result from variations in the amount of lactose.[42] Additionally, research suggests that magnesium may mediate the association between milk intake and central obesity, while calcium may mediate the effect of yogurt, and magnesium and phosphorus the effect of cheese on metabolic syndrome in adults.[37] Other research in adults in which yogurt was specifically examined have found negative associations between yogurt and weight gain. A 3-month RCT in 34 adult participants found a significant decrease in body weight and body fat with consumption of three servings of fat-free yogurt per day.[20] Further, a study of three prospective adult cohorts found a significant inverse association for 4-year weight gain with yogurt consumption (−0.82 lb).[43] Our study did not reproduce these results with yogurt intake among adolescents, perhaps because yogurt consumption was so small in these adolescents (~1/20th of a serving per day on average) compared to adults. Our data, however, showed a significant negative association of total dairy, unflavored milk and reduced fat/low fat/fat-free dairy with BMI *z*-score over time. Other than for total dairy and reduced fat dairy, these findings were also present for the secondary outcomes of BMI and weight. This suggests that these types of dairy products, or the associated dietary or physical activity patterns, may facilitate weight loss during a weight loss program.

There are several proposed mechanisms to explain a possible positive effect of dairy consumption on weight. An increase in calcium intake as a result of greater dairy consumption can reduce lipogenesis and stimulate lipolysis, likely a result of suppressing 1,25-dihydroxyvitamin D formation and secretion of calciotropic and parathyroid hormones.[44] Besides calcium, other dairy components may be responsible for explaining the benefits for body weight and fat loss. Literature has suggested that milk is rich in bioactive peptides that may act independently of calcium to regulate accumulation of body fat.[45,46] Milk bioactive peptides (casokinins and lactokinins) have been found to inhibit angiotensin-converting enzyme, and thus production of angiotensin II hormone, resulting in reduction of fat deposition. Whey protein promotes glucose metabolism control in insulin-resistant subjects, promotes satiety through increased release of anorectic gut hormones such as leptin and GLP-1, and decreased release of the orexigenic hormone ghrelin.[45,47–49] Additionally, conjugated linolenic acid, a family of fatty acids present in dairy foods, may regulate adipogenesis, inflammation and lipid metabolism to produce antiobesity effects.[50] With benefits of carbohydrate (lactose) and protein (whey and casein), milk is also considered a healthy substitute to energy dense beverages; it may reduce hunger and improve compliance to a healthy diet.

What this study adds

This is the first known longitudinal study suggesting that unsweetened milk and low fat/fat-free dairy products, and possibly total dairy and reduced fat dairy products, may contribute to successful weight loss in adolescents participating in behavioral obesity treatment. This association may be due to co-occurring healthier lifestyle factors or to the replacement of other high energy density food and beverages by these dairy products. A clinical trial designed to randomize obese adolescents to a weight loss program with or without an emphasis on promotion of unsweetened milk and low fat/fat-free dairy products may provide support for a causal link between these foods and success in obesity treatment of adolescents.

Limitations of this study

This study had several limitations. Because this was an observational study, causal inference is limited. The sample size was not large enough to test interactions by sex or intervention type. The adolescents that participated in this study may not be representative of the general population since they agreed to participate in a weight loss intervention and are possibly more motivated due to obesity. However, if the associations between dairy and weight observed in our study are a result of physiological mechanisms, it is unlikely these would be different among other adolescent groups. Strengths included rigorous measurements of dietary intake and weight status, as well as findings consistent with the *a priori* determined hypothesis and primary outcome. A loss to follow-up rate of <10% over 12 months is another strength of the present study.

To conclude, the hypothesis that dairy products may be associated with successful weight loss by replacing more energy dense foods and beverages is supported by our finding that the observed association of total dairy, unflavored milk and reduced fat/low fat/fat-free dairy with changes in BMI *z*-score was no longer significant after adjustment for other dietary and physical activity patterns. While these incidental findings should be interpreted with caution, it is possible that either dairy intake is just associated with other healthy lifestyle factors or, as suggested by our results, that this intake in fact replaces other foods and beverages independently associated with weight gain, such as sugar-sweetened beverages,[51] or both.

Acknowledgements

The authors thank the study subjects, their families, the study staff, and the staff of the Nutrition and Growth Laboratory at The Children's Hospital of Philadelphia.

Funding

The work was supported by National Institutes of Health (Grants R01 HD049701 and UL1 RR 024134) and the Dairy Research Institute.

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