Dairy Consumption and Female Height Growth: Prospective Cohort Study

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Abstract

Background: **Because of its nutrients and anabolic hormones, cow's milk may promote height growth, which in turn has been related to breast cancer risk. We prospectively investigated associations between dairy intakes and height growth.**
Methods: **A cohort of 5,101 girls from throughout the United States completed annual surveys (1996-2001, 2003), providing height, weight, and past-year diet. At baseline, all were premenarchal, ages 9 years and above, with no serious medical conditions. We studied three outcomes: annual height growth, peak growth velocity, and adult height. Multivariate models estimated the effects of milk, cheese, yogurt, and energy on subsequent growth, adjusted for race/ethnicity, age, prior height, and body mass index. Other models studied fats and proteins.**
Results: **Premenarchal girls who drank >3 servings per day of milk grew 0.11 in. ($P = 0.02$) more the following year than girls consuming <1 serving per day. Yogurt (+0.13 in./cup; $P = 0.02$), but not cheese or total calories, predicted height growth. In a separate model, dairy protein (+0.034 in./10 g; $P < 0.001$) predicted height growth. Larger peak velocities were seen among girls reporting, at baseline, more milk (>3 glasses per day versus <1; +0.14 in., $P = 0.01$), more yogurt (+0.17 in./cup, $P = 0.02$), and, in a separate model, more dairy protein (+0.039 in./10 g; $P = 0.003$). Baseline milk and dairy protein predicted taller adults. Dairy protein was more important than dairy fat, for all outcomes. Nondairy animal protein and vegetable protein were never significant, nor were nondairy animal fat and vegetable fat.**
Conclusion: **Of the foods/nutrients studied, dairy protein had the strongest association with height growth. These findings suggest that a factor in the nonlipid phase of milk, but not protein itself, has growth-promoting action in girls.** (Cancer Epidemiol Biomarkers Prev 2009;18(6):1881–7)

Introduction

Research on the effect of dietary intakes upon height growth in children, using longitudinal cohort studies, goes back decades. These original studies were interested in the relationship between malnutrition and inadequate physical growth. Although height has a genetic component, observed secular trends in growth during decades of dietary improvements (1) and studies of immigrant and refugee children whose growth rates, soon after their arrival in the United States, matched or exceeded those of U.S. white children (2) show the importance of the nutritional environment. There is renewed interest in the investigation of factors, including milk and other dairy products, which may promote height growth in today's youth. Recent studies suggested that more rapid childhood height growth may be a factor in the development of cancer, especially breast cancer in women (3-5). Longitudinal studies have implicated milk specifically, rather than animal protein, as being associated with more rapid growth in the fetus and child (6-9).

In this study, we investigated the consumption of cow's milk, cheese, yogurt, dietary protein, and dietary fat in relation to 1-year height growth, peak height growth velocity (PHV), and eventual adult height in a large cohort of girls each having up to 8 years of follow-up.

Materials and Methods

Subjects. Established in 1996, the Growing Up Today Study includes 8,980 girls from all 50 states who are daughters of Nurses' Health Study II participants (10). The study, approved by Human Subjects Committees at Harvard School of Public Health and Brigham and Women's Hospital, is described elsewhere (11). Mothers provided informed consent and their daughters assented by completing baseline questionnaires. The cohort, ages 9 to 14 y in 1996, returned follow-up questionnaires annually through 2001 and again in 2003. The girls' response rate to one or more of these follow-ups after baseline was 96%, and >80% of the girls remained in the study 6 or more years by providing data in 2001 and/or 2003.

Received 12/5/08; revised 3/7/09; accepted 4/1/09; published online 6/8/09.

Grant support: NIH grant DK46834 (Bethesda, MD) and a grant from The Breast Cancer Research Foundation (New York, NY).

Note: All five authors contributed to the collection of data from the Growing Up Today Study cohort over the years; Drs. C.S. Berkey, G.A. Colditz, and W.C. Willett conceived the hypotheses investigated in this report; all authors participated in the design of this particular study; Dr. C.S. Berkey did the analyses and drafted the report; Dr. G.A. Colditz obtained the funding; all authors contributed to the interpretation of the data and the writing/revision of the report.

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doi:10.1158/1055-9965.EPI-08-1163

Table 1. Baseline characteristics of premenarchal girls by white dairy milk consumption

	Glasses of milk/d			
	0-<1	1	2-3	>3
n	1,768	1,126	2,019	600
Age (y)	11.3	11.3	11.1	11.3
White race/non-Hispanic (%)	94.3	94.3	96.5	97.3
Height (in.)	57.7	57.8	57.8	58.1
BMI (kg/m^2)	18.4	18.1	18.0	18.2
Height growth (in.) from 1996-1997	2.5	2.5	2.5	2.6
Age at PHV (y)	12.6	12.6	12.5	12.6
PHV (in./y)	3.1	3.1	3.2	3.3
Adult height (in.)	65.3	65.4	65.7	65.9
White + chocolate milk glasses/d	0.6	1.2	2.8	4.3
Calories/d	1,829	1,978	2,197	2,360
Cheese (slices/d)	0.37	0.41	0.45	0.50
Yogurt (cups/d)	0.10	0.12	0.13	0.14
Dairy fat (g/d)	13.1	15.1	19.2	23.4
Nondairy animal fat (g/d)	16.6	17.3	18.5	18.2
Vegetable fat (g/d)	34.1	35.6	36.5	36.9
Dairy protein (g/d)	15.0	20.5	33.5	46.2
Nondairy animal protein (g/d)	25.8	27.2	29.1	28.1
Vegetable protein (g/d)	23.0	24.5	25.9	26.4

NOTE: Girls with serious medical conditions and those who drank soymilk at baseline were excluded.

Only girls who were premenarchal at baseline (*n* = 5,851) were eligible to be included in these analyses. Of these, 295 girls (5%) had a serious medical condition (reported by mother) that might affect growth and were therefore excluded entirely, leaving 5,556 girls available for these analyses. The number of girls in each analysis below will depend on the specific outcome and exposures studied. For example, some girls who do not provide an adult height will provide a peak growth velocity or one or more annualized height growth increments before menarche; other girls may not provide a peak velocity but will provide an adult height. Thus, the actual group of girls analyzed and their sample sizes will vary between models in our approach that uses all available data for studying each outcome.

Growth Data. Children reported their heights and weights on every survey. Our questionnaire provided specific measuring instructions but suggested they seek assistance; their mothers (nurses) biennially self-report their own heights and weights for Nurses' Health Study II. An analysis of National Health and Nutrition Examination Survey (NHANES) III adolescents supported high validity for self-reported height and weight (12). We assessed relative weight status by computing the body mass index [BMI = weight/height^2 (kg/m^2)]. The validity of self-reported BMI was shown by National Longitudinal Study of Adolescent Health analyses that found a high correlation between BMI computed from measured values and from self-reports by youth in grades 7 to 12 (13).

From the serial heights provided by each girl, we computed a series of annualized height growth increments, $\mathrm{HT}_t - \mathrm{HT}_{t-1}$, divided by the time interval (in years, to the month) between adjacent survey return dates. Whenever an annual survey or height was missing, we computed annualized height growth from surveys 2 y apart when possible. Seventy-eight percent of the cohort provided 3, 4, 5, or 6 annualized height growth increments. A total of 5,101 girls (with no serious medical diagnoses) provided one or more annualized height growth increments, in which they were premenarchal when the interval began. After inspecting a girl's series of annualized growth increments, we designated the largest of these as her PHV (in./y). Each girl's adult height was her greatest height attained after menses-onset; girls who provided no heights after menses began had missing adult height. As the median of the girls' oldest observed ages was 17.8 y, growth should be completed for most.

Dietary Intakes. We used a self-administered semiquantitative food frequency questionnaire (FFQ), designed specifically for older children and adolescents (14). This FFQ for youth has good validity and reproducibility for children ages 9 through 18 y (14, 15); the mean correlation for nutrients from the FFQ compared with three 24-h recalls was $r = 0.54$, comparable with the performance of a similar adult FFQ. Milk and dairy products, including yogurt and cheese, had particularly high validity among adult women (16). Another youth FFQ, similar to ours, provided estimates of milk and dairy food consumption by adolescent girls that correlated well with 7-d dietary records (17).

Our 1996 through 2001 annual surveys each inquired about the usual frequency of intake over the past year of milk, cheese, and yogurt. The white milk question indicated that the serving size was a "glass or with cereal"; for chocolate milk, the serving was a "glass"; the cheese serving was "1 slice"; and a yogurt serving was "1 cup-not frozen." We combined white and chocolate milk to get servings per day of dairy milk. Children also reported the fat content of the milk they usually drink (whole, 2%, 1%, or skim). We derived total dietary fat, dairy fat, vegetable fat, nondairy animal fat (from meat/fish/eggs), total dietary protein, dairy protein, vegetable protein, nondairy animal protein (from meat/fish/eggs), and total energy intakes. Dairy fat and dairy protein were calculated from milk, butter, yogurt, and cheese as whole foods and as ingredients in other foods. Regarding any girl who ever reported soymilk intake, her soymilk follow-up years were excluded from these analyses (0.62% of person-y), but her dairy milk intakes were retained in analyses.

Other Variables. At baseline, children reported their race/ethnic group by marking all of the six options that applied to them. We assigned each child to one of five race/ethnic groups following U.S. Census definitions, except we kept Asians as a separate group rather than being pooled with "Other." At baseline, each girl further reported her Tanner maturation stage, a validated self-rating of sexual maturity (18) that uses five illustrations for stage of pubic hair development. Annually, the girls reported whether their menstrual periods had yet begun. We computed each child's age on each survey from dates of birth and questionnaire return.

Statistical Analyses. Our first series of analyses related dietary intakes to height growth during the following year. We studied only height increments for which the girl was premenarchal at the start of the time interval because most growth occurs before onset of menses. We fitted linear regression models of annualized height growth on prior diet, adjusting for age [nonlinear: age (minus 11.5), age^2, and age^3], race/ethnic group, prior height, and prior relative BMI girl's BMI − age-specific median BMI, from Centers for Disease Control and Prevention (CDC) growth charts (19). Because each girl can have multiple 1-y height growth increments, the assumption of independent observations as required by ordinary linear regression models is not met. Therefore, we used mixed linear regression models (20) with estimation by SAS proc mixed (21) to take into account correlations among the repeated observations. We used continuous measures of dietary exposures [daily servings of milk (white and chocolate), cheese, yogurt, daily total energy, dietary fat, and protein intakes] to model linear associations with height growth. In separate models, we used categorical white milk intake, to observe and estimate any nonlinear trends, as we were particularly interested in high intakes (>3 servings per day). Categorical chocolate milk was a separate variable in all models in which categorical white milk appeared. Protein and fat were studied as dietary totals (total protein, total fat) and also separately as dairy, nondairy animal, and vegetable. Some models adjusted for total energy intake to address the possibility that girls consumed more dairy products because they were in a period of rapid growth; if they were eating more dairy products, as a result of growth-induced hunger, they would likely be consuming more of other foods as well. In some models, prior year diet was replaced by the cumulative average of all prior intakes back to baseline.

Our second series of analyses investigated baseline dietary intakes and PHV, and our third series of analyses similarly investigated baseline diet and eventual adult height. Regression models of these outcomes adjusted for race, nonlinear age, Tanner stage, height, and relative BMI, all at baseline. We focused on baseline data because we wanted to assess the effect of diet recorded far in advance of the outcomes so that reverse causation was not a plausible explanation for our findings. However, we also fit some further models that used cumulative early dietary intakes.

Our estimated regression model βs may be biased due to dairy-intake reporting errors; thus, we investigated the effect of dietary measurement error in two ways. First, we assessed whether conclusions changed when we instead used cumulative averages for milk, cheese, yogurt, and calories over multiple prior years to reduce bias due to measurement error (22). Second, we used the validation study of individual foods on adult women (16) to obtain adjusted effect estimates that take into account measurement error (methods available from authors).

We illustrated the age-specific effects of drinking high amounts of dairy milk all through adolescence by focusing on those girls who were youngest at baseline. We fitted a model to white, non-Hispanic girls who were ages 9, 10, or 11 y, and premenarchal, at baseline (*n* = 3,328). The dependent variable was adult height. Independent variables included dairy milk intakes (categorical) in 1996, 1997, 1998, 1999, and 2000 (each a separate variable in the model), baseline height, baseline age, and baseline Tanner stage. We used model estimates to prepare a figure that shows the height growth curves, from age 10 y to adult, of the highest milk intake and lowest milk intake groups.

Results

Most participants, daughters of Nurses' Health Study II nurses, are white/non-Hispanic (95%). Table 1 shows means (unadjusted), within categories of white milk intake, of age, anthropometric measures, and dietary intakes, at baseline. The largest proportion (37%) of girls reported 2 to 3 servings per day of white milk, and 11% reported >3 servings per day. Chocolate milk consumption was very low, with only 20% reporting >1 glass per week (not shown). Girls who at baseline consumed the most white milk (>3 servings per day) grew slightly more the following year (1996-1997), had slightly higher PHVs, and became slightly taller adults (Table 1).

Associations between dietary intakes and following year height growth were studied in 5,070 girls (analytic sample size after excluding person-years with soymilk intake or missing adjustment variables). Six models are summarized in Table 2. Large white milk intakes (>3 servings per day compared with <1 per day) were significantly associated with greater height growth the following year (models 1-3, Table 2). Yogurt consumption was also associated with greater height growth,

Table 2. Dairy intakes preceding 1-y height growth in premenarchal girls

	Height growth difference (in.) over 1-y					
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	Milk	Milk	Milk	Milk	Per 10 g:	Per 10 g:
	>3 vs <1	>3 vs <1	>3 vs <1	(White + chocolate)	Dairy fat	Dairy protein
β	+0.120	+0.112	+0.108	+0.024	+0.033	+0.034
(*P*)	(0.003)	(0.007)	(0.017)	(0.019)	(0.016)	(0.001)
	2-3 vs <1	Cheese	Cheese	Cheese	Animal* fat	Animal* protein
β	+0.029	+0.014	+0.004	+0.004	−0.015	−0.010
(*P*)	(0.296)	(0.502)	(0.866)	(0.855)	(0.395)	(0.280)
	1 vs <1	Yogurt	Yogurt	Yogurt	Vegetable fat	Vegetable protein
β	+0.004	+0.094	+0.133	+0.126	+0.011	+0.015
(*P*)	(0.895)	(0.061)	(0.019)	(0.027)	(0.337)	(0.353)
			Calories/100 kcal	Calories/100 kcal		
β			+0.002	+0.002		
(*P*)			(0.293)	(0.284)		

NOTE: All linear mixed regression models are adjusted for race, age, age^2, age^3, prior height, and prior relative BMI. Estimated β values are per daily serving or other shown daily quantity. Models 1 to 3 compare servings per day of milk to lowest intake (<1 serving per day) group. Sample sizes range from 5,070 girls (model 1) to 5,024 girls (model 4). Models 1 to 3 include categorical white milk (results shown for >3 versus <1 glasses per day) and categorical chocolate milk (not shown). Model 4 includes white + chocolate milk (glasses per day, continuous). Cheese serving is 1 slice; yogurt is 1 cup.

*Dairy intakes are excluded from animal fat and animal protein grams.

Table 3. Baseline diet of premenarchal girls and PHV

	PHV difference (in. over 1 y)					
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	Milk >3 vs <1	Milk >3 vs <1	Milk >3 vs <1	Milk (white + chocolate)	Per 10 g: Dairy fat	Per 10 g: Dairy protein
β	+0.165	+0.159	+0.140	+0.039	+0.007	+0.039
(*P*)	(0.003)	(0.004)	(0.014)	(0.003)	(0.705)	(0.003)
	2-3 vs <1	Cheese	Cheese	Cheese	Animal* fat	Animal* protein
β	+0.039	+0.001	−0.008	−0.007	−0.033	−0.012
(*P*)	(0.314)	(0.960)	(0.765)	(0.794)	(0.151)	(0.352)
	1 vs <1	Yogurt	Yogurt	Yogurt	Vegetable fat	Vegetable protein
β	−0.074	+0.138	+0.169	+0.167	+0.028	+0.026
(*P*)	(0.099)	(0.057)	(0.024)	(0.026)	(0.068)	(0.222)
			Calories/100 kcal	Calories/100 kcal		
β			+0.002	+0.001		
(*P*)			(0.498)	(0.603)		

NOTE: All models are adjusted for race, age, age^2, age^3, Tanner stage, height, and relative BMI, all at baseline. Estimated β values are per daily serving or other shown daily quantity. Models 1 to 3 compare servings per day of milk to lowest intake (<1 serving per day) group. Sample sizes range from 5,022 girls (model 1) to 4,975 girls (model 4). Models 1 to 3 include categorical white milk (results shown for >3 versus <1 glasses per day) and categorical chocolate milk (not shown). Model 4 shows results for white + chocolate milk (glasses per day, continuous). Cheese serving is 1 slice per day; yogurt serving is 1 cup per day.

*Dairy intakes are excluded from animal fat and animal protein grams.

but cheese and total energy intake (from all foods and beverages) were not (models 3 and 4, Table 2). Total milk intake (white and chocolate), modeled as servings per day, was also associated with subsequent height growth (model 4, Table 2). Our conclusions were identical when cumulative prior intakes of milk, cheese, yogurt, and calories were analyzed instead of the single prior year (not shown). Our conclusions were unchanged when we adjusted for total fat and total protein instead of total energy intake (not shown). An analysis of dairy fat, animal (excluding dairy) fat, and vegetable fat together suggested that only dairy fat was associated with subsequent height growth (model 5, Table 2). The analysis of sources of dietary protein similarly found that only dairy protein was associated with subsequent growth (model 6, Table 2). Including dairy fat and dairy protein together in a model indicated that dairy protein (β = +0.03/10 g, *P* = 0.015), rather than dairy fat (β = +.012/10 g, *P* = 0.461), was the nutrient associated with height growth. When we included dairy protein in models along with milk, then milk was no longer significant (not shown); however, keep in mind that milk and dairy protein are very highly correlated (*r* = +0.88 at baseline).

The mean age at PHV was 12.6 years (SD 1.4), and the mean PHV was 3.2 (SD 1.3) in./y. This means PHV is similar to that reported on two earlier female cohorts [whites: 3.1 in./y (23); whites: 3.2 in./y, blacks: 3.3 in./y (24)], in which heights of children were measured by study personnel rather than self-reported as in our study. Occurrence of PHV at younger ages was associated with more growth during the peak year; for instance, among those whose peak growth occurred at age 9 years, they grew 4.1 in. over 1 year on average, whereas those with peak growth at age 14 years grew only 2.2 in. during the year. This age-dependent pattern for PHV is comparable with that observed in a longitudinal cohort of U.S. girls (25) followed during the 1970s. We have 5,022 Growing Up Today Study cohort girls for studying associations between baseline diet and PHV (Table 3), after excluding those who drank soymilk at baseline and those with missing adjustment variables. Higher milk and yogurt intakes at baseline predicted larger peak velocities (models 3 and 4, Table 3); conclusions were identical when we instead analyzed cumulative prior intakes (not shown). Baseline dairy protein (model 6, Table 3) predicted larger PHVs. Conclusions about milk and yogurt were similar when we adjusted for total fat and total protein, instead of energy, but milk was no longer significant when dairy protein was included in the same model (not shown).

The mean adult height was 65.5 (SD 2.8) in. We had 4,870 girls for the analysis of early diet and adult height, after excluding girls who drank soymilk at baseline or who had missing adjustment variables. Those who reported higher baseline milk intakes became taller adults (Table 4, models 1-4). Analysis of cumulative prior diet provided the same conclusions (not shown). Replacing calories in models 3 and 4 with total fat and total protein intake also did not change these findings (not shown). Dairy fat (model 5) and dairy protein (model 6) at baseline both predicted taller adults. Dairy protein (β = +0.072/10 g, *P* = 0.008) was more important than dairy fat (β = −0.009/10 g, *P* = 0.806) when modeled simultaneously (model not shown). When dairy protein was added to models 1 and 2, milk was no longer significant (not shown).

Dairy-intake reporting errors are likely nondifferential with respect to subsequent height growth. We showed above, for all three outcomes, that conclusions were identical when we instead used cumulative averages for milk, cheese, yogurt, and calories over multiple prior years, suggesting minimal bias in our estimated βs due to dietary measurement error. We also obtained adjusted estimates that take into account measurement error. These adjusted βs for milk were 2.5 times larger than those shown in Tables 2, 3, and 4 (model 4). For example, the Table 2 (model 4) estimated milk effect of +0.024 in./serving becomes +0.06 after correction for measurement error. The corrected milk βs for adult height (Table 4, model 4) is 0.19 in./serving, so that a girl who at baseline reported 4 servings per day is expected to be nearly 0.80 in. taller in adulthood.

Figure 1 illustrates the long-term effect of drinking >3 servings per day of milk from ages 10 years to adulthood, relative to girls who consistently drink <1 serving per day throughout. Also shown is the existing height difference at age 10 years, between the high and low milk intake groups. We believe these baseline differences in height exist because girls who consumed high amounts of milk had probably been doing so for years before entering our study, and conversely for those who drank little or no milk at baseline. The average net difference in eventual adult height is nearly 1 in., although with consideration of measurement error, this may be closer to 2 in.

Discussion

In this large cohort of girls, 80% of whom were followed at least 6 years, we found that intakes of dairy milk, yogurt, and dairy protein were positively associated with height growth during the following year; baseline intakes of these were also associated with PHV. Baseline milk and dairy protein were similarly associated with eventual adult height. We found no evidence that cheese intakes were relevant to any of our growth outcomes. Analyzing cumulative prior dietary intakes provided the same conclusions (as described above) for all outcomes and all exposures. When modeled together, dairy protein, but not dairy fat, was associated with later height growth. We also considered models (not shown) that included milk type (whole, 2%, 1%, skim) along with milk quantity, and these models likewise did not support a role for dairy fat. Of particular interest is that dairy protein was associated with subsequent height growth, but nondairy animal protein and vegetable protein were not significant in any of our models, suggesting that protein itself is not the growth-promoting factor. The protein in milk may be a marker for other factors in the nonlipid component of milk, because adding dairy protein to models of milk intake greatly diminished the milk association. By analyzing dietary intakes reported before height growth outcomes, and by including total energy intake and/or multiple dietary factors within some models, the likelihood is enhanced that the associations we observed are causal.

Note that yogurt was a significant predictor of following year height growth and of PHV but not of adult height. We believe that this is due to two factors: adult height is a much later outcome than annual height growth or PHV, and correlations between baseline yogurt and later yogurt intakes were far lower than the correlations between baseline milk (or cheese) and later year intakes. The correlation between 1996 and 1997 total milk was 0.55, but only 0.36 between 1996 and 1997 yogurt intakes.

Our findings are generally consistent with earlier longitudinal studies. Adolescent boys who consumed the most total protein had higher height growth velocity curves than low-protein consumers (26), and similarly for preschool boys and girls (27). Girls who consumed more (energy adjusted) animal protein 2 years before peak growth had higher peak velocities (23). Unfortunately, those studies did not separate dairy from other animal protein. From the National Health and Nutrition Examination Survey (NHANES) data, childhood milk consumption was positively associated with adolescent and adult height (9). New Zealand children with a history of cow milk avoidance were shorter (28). A school-based milk intervention trial in Chinese girls showed benefits for bone growth and also significantly greater height growth over 2 years (8). A longitudinal study of 92 Japanese children found greater 3-year height growth among children who drank more milk (7). Our findings were also consistent with a pregnancy study in which infant birth length was related to maternal milk intake; interestingly, maternal dairy protein intake was linked to birth weight, but dairy fat, cheese, and nondairy protein were not (6).

The mechanism whereby dairy consumption promotes height growth in girls needs to be understood. Recent trials of Mongolian children and Boston children found that drinking milk increased somatotropic hormone [growth hormone insulin-like growth factor I (IGF-I), and IGF-binding protein-3 (IGFBP-3)] concentrations in prepubertal children, and the Mongolian children experienced rapid

Table 4. Baseline diet of premenarchal girls and eventual adult height

	Adult height difference (in.)					
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	Milk >3 vs <1	Milk >3 vs <1	Milk >3 vs <1	Milk (white + chocolate)	Per 10 g: Dairy fat	Per 10 g: Dairy protein
β	+0.318	+0.317	+0.297	+0.076	+0.066	+0.068
(*P*)	(0.001)	(0.001)	(0.003)	(0.001)	(0.040)	(0.003)
	2-3 vs <1	Cheese	Cheese	Cheese	Animal* fat	Animal* protein
β	+0.198	−0.001	−0.005	−0.009	−0.013	−0.025
(*P*)	(0.003)	(0.989)	(0.915)	(0.845)	(0.748)	(0.265)
	1 vs <1	Yogurt	Yogurt	Yogurt	Vegetable fat	Vegetable protein
β	+0.024	−0.043	−0.055	−0.040	−0.020	+0.025
(*P*)	(0.757)	(0.735)	(0.668)	(0.755)	(0.451)	(0.495)
			Calories/100 kcal	Calories/100 kcal		
β			+0.001	+0.000		
(*P*)			(0.806)	(0.941)		

NOTE: All models are adjusted for race, age, age^2, age^3, Tanner stage, height, and relative BMI, all at baseline. Estimated β values are per daily serving or other shown daily quantity. Models 1-3 compare servings per day of milk to lowest intake (<1 serving per day) group. Sample sizes range from 4,870 girls (model 1) to 4,829 girls (model 4). Models 1 to 3 include categorical white milk (results shown for >3 versus <1 glasses per day) and categorical chocolate milk (not shown). Model 4 shows results for white + chocolate milk (glasses per day, continuous). Cheese serving is 1 slice per day, and yogurt is 1 cup per day.

*Dairy intakes are excluded from animal fat and animal protein grams.

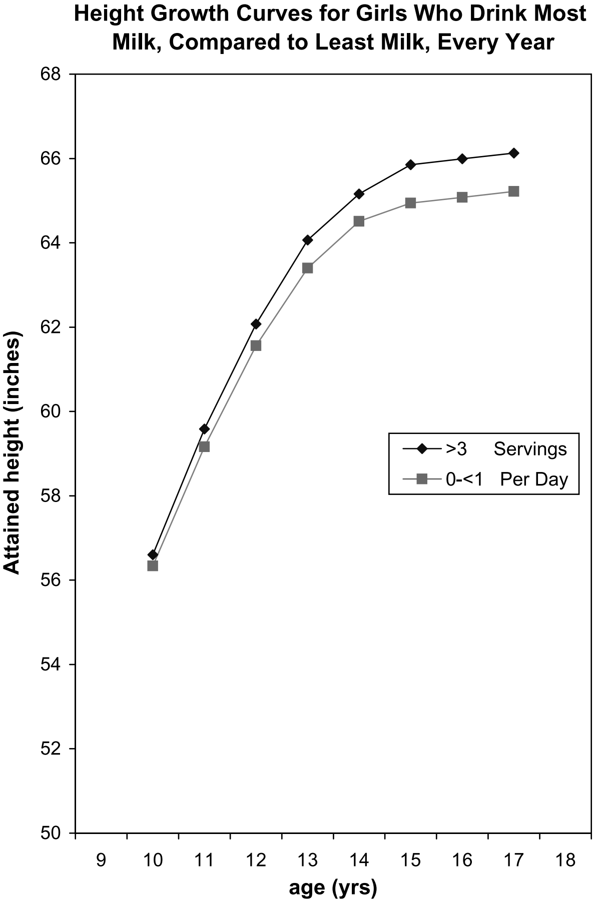

Figure 1. Difference in attained height growth curves between girls who consistently drink >3 servings/d and those who consistently drink <1 serving/d. Curve differences were estimated from models fit to n = 3,328 girls (white, non-Hispanic) who were aged 9 to 11 y and premenarchal at baseline (1996). Preexisting height difference between milk groups at baseline is shown.

linear growth during the month-long milk intervention (29). In a randomized trial, milk supplementation increased IGF-I levels in 12-year-old girls (30). Other intervention trials similarly found increased blood concentrations of IGF-I associated with milk intake (31, 32). In a cross-sectional study of 2-year-olds, milk intake was positively associated with higher concentrations of IGF-I in blood and with taller height (33), although another cross-sectional analysis of 7- to 8-year-old girls found no associations among milk/dairy intakes, IGF-I, or height (34). The reason that our study showed positive associations with milk but not with cheese may be that fermentation of cheese alters the biological activity of IGF-I in dairy products (35).

A major strength of this analysis was the longitudinal design of our study, in which height and weight measurements and dietary intakes were obtained annually on a large cohort of girls from all over the United States. Longitudinal observational studies such as ours cannot determine causality as validly as randomized controlled trials; however, our study design is superior to cross-sectional studies, in which associations may represent reverse causality. Although we controlled for potential confounders in our models, some residual and unmeasured confounding may remain. We cannot exclude the possibility of incomplete adjustment of some covariates, or confounding through variables not considered. Because we included total energy intake in some models and other models included all sources of protein simultaneously, or all sources of dietary fat simultaneously, we have minimized the possibility that higher dairy intakes were the result of rapidly growing (hungry) children rather than the cause. Although our cohort is not representative of U.S. girls, associations among factors within our cohort should still be valid. Because all participants are daughters of nurses, this reduces confounding by socioeconomic and other unmeasured factors, as well as enhances the accuracy of the information they provide. But the racial and ethnic makeup of our cohort (95% white/non-Hispanic) limits the generalization of our findings.

The major limitation of our study was the necessity to collect data by self-report on mailed questionnaires; however, with our large, geographically dispersed cohort, alternatives were not feasible. Errors in reporting dairy foods and beverages are likely to be nondifferential with respect to subsequent height growth, resulting in underestimates of true associations. A food-based validation study of dietary questionnaires (in adult female nurses) found high validity for dairy products and most beverages, including milk (16). Still, we addressed the diet measurement error issue in two ways: by fitting models using cumulative averages of prior dietary intakes to reduce bias due to measurement error (22) and by using the validation study of individual foods (16) to further assess how measurement error may have biased our estimates.

This work is significant because studies in the past decade have suggested that adult height (36); height growth during ages 8 to 14 years (3), 4 to 7 years, and 11 to 15 years (4); and PHV (5) are associated with breast cancer risk. Whether the rapid growth itself or other factors, such as dietary intakes or hormones that may promote growth, are cancer initiators or promoters is unknown. The small number of cohort studies collecting data on childhood milk intake did not consistently support any association between early dairy consumption and adult breast cancer, although most of these studies involved diets recalled later in adulthood (37-40). Studies of dairy products consumed in adulthood, when there are no implications about height growth, had very mixed results about associations with breast cancer; the most recent review of prospective observational studies concluded there was no consistent link (41). In this report, we cannot directly assess risk for breast cancer because our cohort is still too young, but we were able to consider dietary factors that may promote more rapid prepubertal height growth, which may be a critical period for the development of breast cancer or other adult diseases.

These longitudinal analyses of three different height growth outcomes provided evidence that dairy milk and yogurt intakes and dairy protein consumption, but not protein from other sources (nondairy animal and vegetable) or dietary fat or cheese, promote height growth. These findings suggest that a factor in the nonlipid phase of milk, but not protein itself, has growth-promoting activity in prepubertal girls.

Disclosure of Potential Conflicts of Interest

No potential conflicts of interest were disclosed.

Acknowledgments

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