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Lead Article

Dairy product intake in children and adolescents in developed countries: trends, nutritional contribution, and a review of association with health outcomes

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Despite its contribution to nutrient intake and status, consumption of milk and dairy products by children and adolescents in many countries has waned in recent decades, with a substantial proportion of youth failing to meet intake recommendations. Dairy products remain an important dietary source of multiple micronutrients, including calcium, phosphorus, magnesium, zinc, iodine, potassium, vitamin A, vitamin D, vitamin B_{12}, and riboflavin (vitamin B_2). In addition, dairy products provide children with energy, high-quality protein, and essential and nonessential fatty acids. A review of evidence was conducted to evaluate associations between milk or dairy product intake and health outcomes in children and adolescents. Results suggest a neutral or inverse association between consumption of milk and dairy products in children and adolescents and indicators of adiposity, incidence of dental caries, and hypertension. Available data indicate that dairy products are important for linear growth and bone health during childhood. Additional research – in particular, controlled intervention trials and long-term prospective cohort studies – is warranted to better understand how dairy intake affects health outcomes in children and adolescents.

INTRODUCTION

Milk and other dairy products, including cheese, yogurt, other fermented milks, and dairy desserts, provide energy, protein, micronutrients, and bioactive compounds that support growth and development. Despite the recognized advantages of milk and dairy products as components of a nutrient-rich and balanced diet, dairy consumption by children and adolescents in many countries has waned in recent decades, with a substantial proportion of youth failing to meet dairy product intake recommendations. Furthermore, both cross-sectional surveys and longitudinal data suggest a decreasing trend in dairy consumption with age. In addition to compromising the status of micronutrients, including calcium, phosphorus, magnesium, iodine, zinc, potassium, vitamin A, vitamin D, vitamin B_{12}, and riboflavin (vitamin B_2), dairy product consumption below recommended levels may have an adverse impact on bone and dental integrity and maintenance of healthy body composition. The purpose of the present review is to evaluate milk and dairy product intake among children and adolescents in developed countries and to consider how dairy product consumption is related to key nutrient intake and health outcomes.

GLOBAL DAIRY INTAKE RECOMMENDATIONS FOR CHILDREN AND ADOLESCENTS

Recommendations for dairy product intake in developed countries are approximately two–three servings (approximately 500 mL) per day for children under the age of 9 years and three–five servings (>600 mL) per day for adolescents, with a number of national guidelines

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specifically encouraging low-fat dairy products (Table 1). Several countries, including Finland and Belgium, provide specific recommendations for cheese intake (one serving per day) in addition to milk and other dairy products. In Norway and the United Kingdom, in contrast, intake recommendations consist of broad suggestions for daily consumption of low-fat dairy products. In some countries, dairy intake recommendations are based on recommended dietary intakes for calcium, which range from 500–1,300 mg/day for children and adolescents.

DAIRY PRODUCT INTAKE IN CHILDREN AND ADOLESCENTS

National dietary surveys and studies of dairy product consumption by children and adolescents have been conducted in a number of countries in recent years. Most studies have consisted of cross-sectional comparisons among children in different age ranges, while a few have followed the same group of children longitudinally. Although data are available from few countries, the proportion of children and adolescents meeting national dairy product intake recommendations tends to decrease with age through middle childhood and early adolescence (Table S1 in the Supporting Information for this article online).

Dairy product intake trends in children and adolescents

Based on national survey data, milk consumption among children and adolescents has decreased over time in developed countries. From 1977 to 2001, the proportion of children aged 2–18 years in the United States consuming milk decreased from 94% to 84%, the number of servings consumed per day dropped from 3.5 to 2.8, and the portion size of each serving decreased significantly from 460 mL to 410 mL.[1] A study comparing dairy intake by adolescents aged 11–18 years over four nationally representative US surveys conducted from 1965 (Nationwide Food Consumption Survey) through 1994–1996 (Continuing Survey of Food Intake by Individuals [CSFII]) found a decline in milk consumption from 1,181 g/day to 746 g/day in boys and from 848 g/day to 481 g/day in girls that was not compensated by an increase in consumption of other dairy products.[2] Using data from the National Health and Nutrition Examination Surveys (NHANES) conducted in 1989–1991, 2005–2006, and 2007–2008 in the United States, investigators found that overall consumption of milk decreased significantly from 218 kcal/day to 170 kcal/day ($P < 0.05$). Among children, consumption of milk with at least 1% milk fat containing no added sugar decreased significantly (–82 kcal/day), while consumption of flavored milk containing added

Table 1 **Daily dairy recommendations (servings or volume per day) for children and adolescents in select countries.**

Country	Serving size	Recommendation for children	Recommendation for adolescents
Australia	250 mL milk, 200 g yogurt, 40 g cheese	1.5–3 servings (4–11 y)	3.5 servings (12–18 y)
Belgium[a] (Flanders)	150 mL milk, yogurt, fermented milk drinks, or custard, 20 g cheese (< 20% fat by weight)	3 servings of milk products, 1 serving of cheese (3–11 y)	4 servings of milk products, 1–2 servings of cheese (12–18 y)
Belgium (Wallonia)	NA	2–3 servings	3 servings
Canada[a]	250 mL milk, 175 g yogurt, 50 g cheese	2 servings (2–8 y)	3–4 servings (9–18 y)
Denmark	NA	≥350 mL	500 mL (≥250 mL acceptable)
Finland	NA	500–600 mL milk + 20 g cheese	N/A
France	150 mL milk, 125 g yogurt, 30 g cheese	3–4 servings	3–4 servings
Ireland[a]	200 mL milk, 125 mL yogurt, 25 g hard cheese	3 servings (5–8 y)	5 servings (9–18 y)
Israel	200 mL milk, 150 g yogurt, 20 g cheese	2–3 servings	2–3 servings
Japan	90 g milk	2 servings	2 servings
New Zealand[a]	250 mL milk, 150 g yogurt, 40 g cheese, 140 g ice cream	2–3 servings (2–12 y)	≥3 servings (13–18 y)
Norway[a]	NA	“Include daily”	“Include daily”
South Africa	NA	500–750 mL (7–13 y)	250–500 mL (14–18 y)
Spain	NA	3–4 servings	3–4 servings
United Kingdom[a]	NA	“Moderate amount”	“Moderate amount”
United States[a]	240 mL milk, 240 g yogurt, 45 g cheese	2–2.5 servings (2–8 y)	3 servings (9–18 y)

Abbreviations: NA, not available.
[a] Low-fat dairy recommended.

sugar (both below and above 1% milk fat) increased significantly (+19 kcal/day) ($P < 0.05$ for all). There was no significant time trend in consumption of skimmed milk without added sugar.[3]

The Dortmund Nutritional and Anthropometric Longitudinally Designed Study, comprising annual 3-day weighed food records of German children aged 1–13 years from 1986 to 2001, found a negative time trend in milk consumption among children aged 1–3 years (−6.5 g/day/study year) and 4–13 years (−2.8 to −7.4 g/day/study year) ($P < 0.05$ for all except girls, aged 9–13 years). However, a significant positive time trend in cheese (+0.2 to +0.7 g/day/study year) and yogurt (+2.4 to +3.3 g/day/study year) consumption compensated for the decrease in milk consumption in all but the youngest age group ($P < 0.05$).[4] In France, comparison of data from children and adolescents from two national surveys completed in 1999 and 2007 (Etude Individuelle Nationale sur les Consommations Alimentaires) found that total intake of milk, cheese, and fresh dairy products declined by 10%, 12%, and 9%, respectively, in children aged 3–10 years, 11–14 years, and 15–17 years.[5] This trend was attributed to a marked decrease in milk consumption among children aged 3–14 years (15%) and among girls of all ages (20%).[6] According to data from a separate national dietary survey carried out in 2003 and 2007, (Consommations et Comportements Alimentaires des Français), cheese and yogurt consumption by French children declined by 15% and 34%, respectively, while consumption of *fromage frais* increased by 35%, and dairy dessert consumption remained stable.[6]

Factors affecting dairy consumption in childhood

Age. Cross-sectional evidence indicates a decline in milk consumption with age[7–11] (Table 2).[4,5,7,9,12–20] Several studies measuring dairy product consumption longitudinally in the same group of children have corroborated this finding, particularly with respect to milk. In a US study of 151 Caucasian girls followed biennially from age 5 years to 11 years, the proportion of girls consuming milk as a beverage decreased significantly over time ($P < 0.001$). The amount of cheese consumed and the proportion of girls consuming dairy desserts increased ($P < 0.01$) such that total dairy intake was stable over time but below recommended levels at ages 7, 9, and 11 years.[21] A steady trend of decreasing milk consumption and increasing soda consumption was found in 2,371 US girls followed annually from age 9–10 years until age 19 years.[22] Other studies involving both girls and boys have found similar trends.[23,24]

Sex. In respective age cohorts, males consume greater quantities of dairy products than females.[25–29] While part of this difference is explained by physiological needs, adolescent females in particular may be influenced by the misperception that dairy foods are fattening.[30] Frequent dieting has been associated with inadequate consumption of dairy products,[31] and female adolescents may intentionally limit intake of dairy products to lose or maintain weight.[25,31]

Parental influence. In the United States, a growing body of data supports an influence of parental attitude and practice on dairy intake by children. Low family expectations[32,33] and infrequent parental intake[25,33,34] negatively influenced milk consumption patterns across studies. In a cross-sectional survey conducted in nine US states, parents classified as "Dedicated-Milk Providers/Drinkers" were more likely to be older and to identify as non-Hispanic white than other races, and their children aged 10–13 years demonstrated higher intakes of milk and dairy foods ($P < 0.0001$).[35] A study of ethnically diverse dyads of mothers and children aged 3–5 years from families with limited incomes in the United States found a significant correlation between maternal intake and child intake of milk ($r = 0.56$), cheese ($r = 0.39$), and dairy desserts ($r = 0.29$, $P < 0.01$ for all). Data from other countries are not available.[36]

Substitution with other beverages. Decreasing milk consumption is concomitant with an increase in consumption of sweetened beverages.[3,9–11,37–41] The substitution of milk with alternative beverages has variously been attributed to increased autonomy in beverage choice,[9] availability of other beverages in the home,[33] and demographic factors, including income, sex, race, and television-watching habits.[38] Furthermore, secular trends in portion sizes and the popularity of sweetened beverages and fruit juices may influence the substitution of milk with these beverages.[1,38] Based on data from the 1994–1996 CSFII, for each 30-mL reduction in milk consumption by children aged 5–18 years, there is an approximately 126-mL increase in sweetened beverage consumption, with a net increase of 31 kcal (130 kJ) and a loss of 34 mg of calcium for each 30 mL of milk displaced.[38]

Dietary pattern. Several studies have found higher milk consumption and calcium intakes in children and adolescents who eat breakfast,[42–45] in part due to the higher consumption of milk at breakfast compared with other meals.[42] In France, breakfast consumption decreases with age, with 87%, 71%, and 50% of children aged 3–10 years, 11–14 years, and 15–17 years, respectively, consuming breakfast daily.[46] In the United States, an increase in cheese intake may be due to eating more meals away from home; two-thirds of cheese consumption in the United States is

Table 2 **Daily mean (± standard deviation) dairy product intake (g/day) in children and adolescents by country.**

Country	Type of dairy product	Preschool children		School-aged children		Adolescents	
		Boys	Girls	Boys	Girls	Boys	Girls
Australia[12]	All types	434.4 (2–3 y)	416.3 (2–3 y)	362.5 (4–8 y) 411.9 (9–14 y)	319.7 (4–8 y) 312.2 (9–13 y)	445.9 (14–16 y)	287.3 (14–16 y)
Belgium[13,14]	Milk	544.2 ± 240.6 (2.5–4 y)[a] 469.2 ± 193.0 (4–6.5 y)	483.1 ± 213.7 (2.5–4 y)[a] 425.0 ± 198.1 (4–6.5 y)	NA	NA	181.4 ± 151.2 (15–18 y)	139.2 ± 107.6 (15–18 y)
	Cheese	11.0 ± 9.4 (2.5–4 y)[a] 14.2 ± 11.2 (4–6.5 y)[a]	17.1 ± 11.8 (2.5–4 y)[a] 12.6 ± 9.1 (4–6.5 y)[a]	NA	NA	30.5 ± 16.0 (15–18 y)	25.9 ± 12.9 (15–18 y)
France[5]	Milk	NA	NA	205.6 (3–10 y) 182.2 (11–14 y)	186.3 (3–10 y) 149.7 (11–14 y)	168.2 (15–17 y)	116.4 (15–17 y)
	Cheese	NA	NA	18.6 (3–10 y) 23.4 (11–14 y)	18.4 (3–10 y) 16.7 (11–14 y)	19.1 (15–17 y)	16.8 (15–17 y)
	Fresh dairy products	NA	NA	95.1 (3–10 y) 69.0 (11–14 y)	78.5 (3–10 y) 59.6 (11–14 y)	61.1 (15–17 y)	61.9 (15–17 y)
Germany[4]	All types	283 ± 179 (1–3 y)		319 ± 178 (4–8 y)		391 ± 242 (9–13 y)	304 ± 184 (9–13 y)
Ireland[15,16]	Whole milk	NA	NA	238 ± 188		206 ± 232	
	Low-fat milk			28 ± 90		42 ± 122	
	Cheese			8 ± 10		11 ± 17	
	Yogurt			39 ± 43 (5–12 y)		22 ± 36 (13–17 y)	
Singapore[9]	All types	635 (3–6 y)		359 (7–10 y)		NA	
South Africa[17,18]	All types	147 (urban) 102 (rural, 1–5 y)		NA		109 (urban), 31 (rural, ages 10+, including adults)	
Spain[19]	All types	425 (M); 378 (F) (2–24 y)		425 (M); 378 (F) (2–24 y)		425 (M); 378 (F) (2–24 y)	
Spain[20]	All types	NA		367 ± 151 (10.3 ± 0.9 y)	340 ± 141 (10.1 ± 1.1 y)	NA	
United Kingdom[7]	Milk	279		226	180	157	111
	Cheese	8 ± 9		10 ± 12	11 ± 14	11 ± 15	11 ± 13
	Yogurt, *fromage frais*, & dairy desserts	44 ± 37 (1.5–3 y)		35 ± 40 (4–10 y)	35 ± 40 (4–10 y)	22 ± 40 (11–18 y)	18 ± 32 (11–18 y)

Abbreviations: F, females; M, males, NA, not available.

[a] Representative sample of Flemish preschoolers.

derived from commercially manufactured and prepared foods.[47]

Preferred forms of dairy products

Several studies have demonstrated changes in preferred forms of dairy products and in dairy consumption patterns during the transition from childhood to adolescence. In general, there is a decrease in preference for and consumption of milk and an increase in intake of other dairy sources as food and beverage choices and autonomy increase.[4,21]

Among children and adolescents consuming milk, there is a trend toward greater consumption of reduced-fat milk. Consumption of low-fat milk products showed a significant positive trend with time from 1986–2001 among German children aged 1–3 years, 4–8 years, and girls aged 9–13 years participating in the Dortmund Nutritional and Anthropometric Longitudinally Designed Study.[4] A similar trend has been reported in the United States.[2] In France, 83% of milk consumed by the population is semi-skimmed or skimmed, according to national surveys conducted in the past decade.[6] Among Flemish preschool children surveyed in 2002–2003, 72% consumed semi-skimmed milk, though more than 20% of children aged ≥4 years consumed whole-fat milk.[14] Recent results of an ongoing survey in the United Kingdom showed that semi-skimmed or skimmed milk constituted 31%, 54%, and 72%, respectively, of total milk consumed by children aged 1.5–3 years, 4–10 years, and 12–18 years.[7]

Studies in children and adolescents in Singapore and the United States report preference for flavored over plain milk.[9,48,49] In the United States, total milk consumption was significantly greater among consumers than among nonconsumers of flavored milk ($P < 0.05$),[48,49] though intake of added sugars did not differ significantly between groups.[49] According to NHANES data (2003–2006), flavored milk contributes just 3% of the added sugars in the diets of US children and adolescents ages 2–18 years.[50]

DAIRY PRODUCT CONSUMPTION AND KEY NUTRIENT INTAKE AND STATUS IN CHILDREN AND ADOLESCENTS

Milk and other dairy foods are important sources of macronutrients and micronutrients in the diets of children and adolescents (Tables S2 and S3 in the Supporting Information online) and play a role in meeting multiple nutrient intake recommendations.[51] The contribution of dairy foods to the dietary intake of nutrients in children and adolescents is evaluated through dietary surveys. However, few studies have measured biomarkers of nutrient status associated with dairy consumption in children.

Calcium

Calcium is important in the development, growth, and maintenance of bones and teeth as well as in other biological processes, including blood pressure regulation, muscle contraction, and blood clotting.[52] In children and adolescents in the United States, milk contributes 50% or more of total calcium intake.[25,53–56] Milk and cheese used as ingredients in meat, grain, and vegetable mixtures contribute another 20% of dietary calcium, while the remaining 30% is derived from calcium-fortified foods and other natural sources.[53,57] In the Netherlands, data from the Dutch Food Consumption Survey carried out in 2005–2006 indicate that dairy products as a whole contributed 73% of total calcium intake in children aged 2–6 years, while milk alone contributed 25%.[58] In France (2005–2007), dairy products (milk, fresh dairy products, and cheese) contributed 53% to total calcium intake among children and adolescents aged 3–17 years, with approximately half of dietary calcium derived from milk.[59] In addition, a number of investigators have found milk to be a primary indicator of total calcium intake in children and adolescents.[29,36,39,49]

Longitudinal data collected throughout childhood in the United States showed that consuming at least two cups of milk (473 mL) per day was associated with significantly higher mean calcium intake ($P < 0.0001$).[60] In France and Australia, adolescent females whose consumption of dairy products was low also had inadequate calcium intake.[6,12] In many countries surveyed, including Japan, Hungary, Italy, Singapore, and the United States, calcium intakes among children and adolescents fall below recommendations.[4,9,61–64]

Phosphorus

Phosphorus, like calcium, functions in bone and tooth development and maintenance. Phosphorus is critical in cellular energy production and storage and is a component of nucleic acids and phospholipids.[52] Several studies have reported significantly higher phosphorus intakes in children with higher consumption than in children with lower consumption of milk and other dairy products.[11,27,49,60,65,66] Dairy products accounted for 29% and 31% of total dietary phosphorus intake in children in the United States and France, respectively.[59,67]

Magnesium

Magnesium is involved in phosphorylation, DNA transcription, protein synthesis, neuromuscular transmission, and muscle contraction.[52] Milk and dairy products provide an important dietary source of magnesium. A number of investigators have found significantly higher magnesium intakes in children and adolescents with greater dairy consumption.[11,42,49,60,65] Milk intake was positively associated with the likelihood of achieving recommended intakes of magnesium for children and adolescents included in the CSFII 1994–1996 ($P < 0.0001$).[68]

Iodine

Iodine is an essential component of thyroid hormones necessary for thyroid function.[69] Although the iodine concentration of milk varies widely within and between countries, depending on the iodine content of water, soil, and animal feed, season, and use of iodine as a disinfectant of udders and milking tools, studies in many countries have found that cow's milk is a relevant source of dietary iodine.[70–74] In France, dairy was the source of 40% of dietary iodine in children and adolescents, while milk alone supplied 18%.[59] Dairy products and milk accounted for approximately 35% of dietary iodine amongst Flemish preschoolers,[75] while milk provided 38% of dietary iodine in children aged 6–12 years in Germany[76] and 50% of dietary iodine in children aged 4, 9, and 13 years in Norway.[71]

In the Veneto Region of Italy, a highly significant correlation was found between intake of milk and urinary iodine concentration (UIC) in adolescents aged 11–15 years ($P = 0.0005$), while the correlation between use of iodized salt and UIC was not significant.[72] In Spain, the mean UIC of children who consumed milk at least three times a day was significantly greater than that of children who consumed milk less frequently ($P < 0.001$), and the likelihood of being iodine deficient (UIC ≤ 100 μg/L) was significantly inversely associated with the frequency of milk intake ($P < 0.05$).[74]

Zinc

Zinc is a cofactor for enzymes involved in DNA, RNA, and protein synthesis and is also a component of insulin.[52] Milk and milk products are a key dietary source of zinc in children, accounting for 16%, 25%, and 39% of total zinc intake in children in the United States, France, and the Netherlands, respectively.[58,59,67] Data collected longitudinally in US children from ages 3–5 years at baseline to 15–17 years indicate significantly greater zinc intake in children habitually consuming at least two versus fewer servings of dairy foods per day ($P = 0.009$).[60] In children aged 3–14 years in Greece, consumption of milk at least six times per week was an independent predictor of serum zinc ($P < 0.001$).[77] A significant positive correlation was also found between intake of milk products and serum zinc in 11-year-old Polish boys and girls ($P < 0.05$).[78]

Potassium

Potassium is an essential dietary mineral and electrolyte that is responsible for maintenance of membrane potential and blood pressure and acts as a cofactor for several enzymes.[79] Milk and milk products were the single most substantial dietary source of potassium among children and adolescents in the United States, accounting for 22% of total potassium intake.[68] Dairy products accounted for 21% of total potassium intake among children and adolescents in France, with 13% provided by milk alone.[59] Potassium intake was significantly higher among children with greater habitual dairy product intake in two studies.[49,60]

Vitamin A

Vitamin A plays a role in skin health, vision, reproduction, immunity, and gene regulation.[52] According to data from NHANES 2001–2008, milk and dairy products constituted the single largest dietary source of retinol (42%) and total vitamin A (34%) for children and adolescents aged 3–19 years.[67] In French children, dairy products contributed 24% of total retinol intake.[59] Energy-adjusted vitamin A intakes were significantly higher in US children and adolescents who drank milk (>60 mL/day) compared with those who did not ($P < 0.05$).[49] It is important to note that commercial cow's milk is routinely fortified with vitamin A in some countries, including the United States and Sweden, but not in others.

Vitamin D

Vitamin D is involved in calcium balance, cell differentiation, and immune function.[80] While vitamin D is naturally present in milk only in trace amounts (2 IU/100 g),[81] milk is fortified with vitamin D in some developed countries. In the United States, nearly all of the commercial milk supply is voluntarily fortified with 41 IU/100 g,[80] though the actual amount as measured by the US Department of Agriculture in 24 samples is 51 IU/100 g.[81] In Canada, milk is fortified by law with 35–40 IU/100 g.[82] Dietary vitamin D intakes were significantly higher among US children with greater usual dairy intakes.[60]

Higher intake of vitamin-D-fortified milk has a positive impact on serum 25-hydroxy vitamin D [25(OH)D], the usual biomarker of vitamin D status. In an intervention trial in New Zealand, where few foods are fortified with vitamin D, toddlers aged 12–20 months receiving milk fortified with vitamin D (36 IU/100 g) for 20 weeks had significantly higher serum 25(OH)D concentrations compared with baseline and with a study group receiving a meat intervention ($P < 0.01$).[83] In another study in New Zealand, children in Year 3 (aged 7–8 years) who had received 300 mL of vitamin-D-fortified skimmed milk daily at school for 2 years prior to testing had significantly higher mean serum 25(OH)D than matched controls ($P = 0.01$).[84] A study comparing vitamin D intake and status of 4-year-olds before and after initiation of national vitamin D fortification of milk and margarine in Finland in 2003–2004 found significantly higher intakes ($P < 0.001$) and serum 25(OH)D ($P = 0.002$) following fortification.[85]

Vitamin B_{12}

Vitamin B_{12} occurs naturally only in foods of animal origin. As a cofactor for two enzymes, it is essential for hematopoiesis, energy metabolism, and functioning of the nervous system.[86] Observational studies in adults and adolescents show that dairy product intake is associated with vitamin B_{12} status.[87–89] Using pigs as a model for human intestinal absorption, investigators recently demonstrated significantly higher bioavailability of vitamin B_{12} from cow's milk than from the synthetic form cyanocobalamin ($P < 0.003$).[90]

In children aged 2–6 years in the Netherlands, national food consumption data indicate that dairy products accounted for 59% of vitamin B_{12} intake, while milk alone accounted for 26% of intake.[58] Data from a wider age range of children and adolescents in the United States and France (aged 3–19 years and 3–17 years) found that dairy products accounted for 29% and 23% of vitamin B_{12} intake, respectively.[59,67] In a cohort of US children aged 2–17 years, milk consumption was significantly associated with the likelihood of achieving recommended intakes of vitamin B_{12}.[68]

Riboflavin (Vitamin B_2)

Riboflavin is an antioxidant involved in oxidation-reduction reactions, cellular respiration, and energy metabolism.[91] Dairy products contribute to riboflavin intake, accounting for 29% and 38% of total riboflavin intake among children and adolescents in the United States and France, respectively.[59,67] Among 732 females aged 12–19 years included in CSFII 1994–1996, non-milk drinkers had significantly lower intakes of riboflavin than milk drinkers ($P < 0.05$).[42] In a 2001–2002 national health survey in Taiwan, marginal and deficient riboflavin status in school children was associated with low frequency of dairy food consumption.[92]

Energy and macronutrients

Dairy products are a source of energy, high-quality protein, and lipids in the diets of children. Dairy products accounted for 13% of total energy intake of children and adolescents in the United States in NHANES 2001–2008.[67] In a 2005–2006 national survey of young Dutch children, dairy products accounted for 25% of total energy, while milk alone contributed 6.4%.[58] In Australia, national survey data from 2007 indicated that the contribution of dairy products to total energy decreases with age, with 24.4%, 17.7%, 15.5%, and 14.1% of energy intake provided by dairy products among children aged 2–3 years, 4–8 years, 9–13 years, and 14–16 years, respectively.[12]

Milk protein is of high quality and contains many peptides and bioactive factors that may have specific effects on growth.[93] Milk consumption has been modestly but significantly associated with dietary protein intake in children in several studies in the United States and New Zealand.[11,66,94] Unique dairy proteins and peptides are antihypertensive,[95,96] may suppress adipose tissue oxidative and inflammatory stress,[97] and promote satiety.[98]

Milk and dairy products contain a variety of dietary lipids. Milk fat is structurally distinct from other fats. It is present as complex globules surrounded by the milk fat globule membrane, which is composed of phospholipids and glycoproteins.[99,100] Milk fat consists of 400 fatty acids composed of 4 to 26 carbon atoms, approximately 65% of which are saturated.[101] However, some of the saturated fats in milk have a neutral effect on low-density lipoprotein, a risk factor for cardiovascular disease,[102] and milk fat has consistently been found to raise protective levels of high-density lipoprotein.[103–105] Furthermore, milk is a source of essential fatty acids.

In Australian adolescents aged 13–15 years, dairy products – excluding butter – contributed approximately 21% of total fat intake, 31.5% of saturated fat, 11.8% of omega-3 fatty acids, and 13.8% of alpha-linolenic acid,[106] whereas energy-dense, nutrient-poor foods contributed 47% of total fat and 47% of saturated fat in Australian children aged 2–18 years.[107] In French children and adolescents aged 3–17 years, dairy products (excluding butter) comprised 16% of total fat intake, 23% of saturated fat, 13% of monounsaturated fat, and 13% of omega-3 fatty acids.[108] Dairy products (excluding butter) accounted for 13.2% and 20.1%, respectively, of total fat and saturated fat intakes in Spanish children aged 6–7 years,[109] 20.0% and 34.6%, respectively, of total fat and saturated fat intakes in individuals aged 2–24 years in the Basque Country of Spain,[110] 24% and 39%, respectively, of total fat and saturated fat intakes in US children and adolescents aged 2–18 years,[111] and 8.7–13.4% of total fat intake in German children aged 1–13 years.[4]

REVIEW OF CHILDHOOD AND ADOLESCENT HEALTH OUTCOMES

As an optimal source of macronutrients, micronutrients, and bioactive factors, milk and dairy products play an important role in childhood growth and development.[93]

A number of health outcomes have been investigated in association with dairy product intake, most notably adiposity, bone mineralization, dental health, linear growth, and blood pressure. The following review aims to integrate available data from observational and intervention studies of milk consumption in relation to each of these outcomes in otherwise healthy and well-nourished children and adolescents aged 2–19 years.

Methods

Inclusion/exclusion criteria. Studies were eligible for inclusion in this review if they were original works published in a peer-reviewed journal, involved participants in the age range 2–19 years, measured dietary milk or dairy intake in at least one group of participants cross-sectionally or longitudinally, and measured one or more quantitative outcomes pertaining to the target categories of adiposity, bone mineralization, dental health, linear growth, or blood pressure. Cross-sectional, cohort, case-control, and intervention trials, both controlled and not controlled, were included. Studies were excluded if a single component of milk or dairy (i.e., calcium or dairy protein) was isolated, if an undernourished or diseased population was selected, or if human milk was included as part of total dairy consumption. For the outcome of bone mineralization, studies reporting only bone mineral density rather than bone mineral content (BMC) were excluded on the basis of dynamic bone turnover in children.[112] Inclusion and exclusion criteria were designed to extract a broad range of data in healthy children and adolescents from multiple countries.

Search strategy. Information sources included the searchable databases PubMed, Popline, and Web of Science as well as contact with study authors. Additional studies were identified by reviewing the bibliographies of original research and review articles. Searches were last conducted in September 2012.

The PubMed database was used to search for relevant Medical Subject Headings (MeSH) and general terms for the exposures and specific outcomes. Limits were set on age (2–18 years) and restricted to studies in humans with English abstracts. Human milk was excluded in the search command. Initial searches were restricted to the data fields of title and abstract. Specific terms included in searches for each of the outcomes were as follows. Adiposity: "obesity," "body mass index," "BMI," "waist circumference," "weight," "body composition," and "overweight"; bone mineralization: "bone," "bone mineral content," "BMC," "dual energy X-ray absorptiometry," "DXA," "peripheral quantitative computed tomography," and "pQCT"; dental health: "teeth," "decayed missing filled," "DMF," "dental decay," "caries," and "enamel"; height: "height," "growth," "peak height velocity," "height gain," "taller," and "shorter"; and blood pressure: "blood pressure," "systolic," "diastolic," and "hypertension."

Study selection and data collection. Original research articles identified in database searches and derived from bibliographies of research and review articles were screened for target population, methods, and exposures and outcomes measured. An abstraction table was used to extract and organize key information from studies that met the selection criteria. As part of this process, study level variables, including design, setting, target population, sample size, duration, comparisons, exposure and outcome definitions, and limitations, were summarized. Principal summary measures were associations, difference in means, and relative risk.

Results and discussion

Electronic and manual searches yielded a total of 2,990 publications covering the five outcome areas. Titles and abstracts of these records were screened using inclusion and exclusion criteria, and 118 were selected for full-paper evaluation. Of the full papers, data were extracted from the 78 that met eligibility criteria.

Body composition and energy balance. Of 35 observational and intervention studies included in the present review, 34 reported null and/or inverse associations between dairy intake and BMI, body fat, or energy balance (Table S4 in the Supporting Information online). Of five randomized controlled trials (RCTs), four found no association between dairy intake and measures of adiposity,[65,66,94,113] while one found an inverse association.[114] A single cross-sectional analysis of data from US children aged 2–10 years participating in NHANES 1999–2004 showed a positive association between dairy product intake and BMI.[115] Twenty-three of the 35 studies included in this review analyzed data collected in the United States. Study designs and durations varied widely, and confounders such as total energy intake, physical activity level, pubertal status, and baseline BMI were often not accounted for in the analysis. Most studies did not take into consideration dietary intake plausibility; those that did found a weaker inverse association between dairy intake and adiposity among plausible dietary reporters.[21,116]

A number of hypotheses have been proposed to explain the observations that milk and dairy product intake in children is not positively, and may be inversely, associated with energy balance or body fat. While milk is a nutrient-dense beverage that is linearly associated with energy intake in absolute terms,[117,118] when removed from the diet it is replaced by other potentially energy-dense foods and beverages. Several authors have noted a rise in childhood obesity coinciding with a decline in dairy consumption and an increase in sweetened beverage consumption.[119,120]

In addition to energy balance, specific components of dairy as well as their unique combination may mitigate fat deposition. In animal models and in vitro studies, dietary calcium, including calcium from dairy sources, suppresses calcitriol and calcitriol-stimulated influx of calcium into adipocytes, inhibiting lipogenesis and promoting lipolysis.[121] In human trials, dietary calcium is often but not invariably associated with increased energy expenditure, thermogenesis, and fecal fat loss.[122] Other calcium-independent mechanisms have been proposed, including an effect of angiotensin-converting enzyme inhibitory peptides in whey protein, which limit angiotensin II production and thereby stimulation of adipocyte lipogenesis.[123,124] In energy-restricted mice, a whey-derived angiotensin-converting enzyme inhibitor significantly augmented the effects of dietary calcium on weight and fat loss but had a less pronounced effect than either milk or whey.[125]

There is emerging evidence that protein-rich animal foods, and especially dairy proteins, better support muscle protein synthesis than plant foods. While enhanced anabolism could potentially increase energy expenditure, there is insufficient evidence to draw this conclusion.[126] The branched-chain amino acid leucine, which is relatively abundant in dairy foods, may play a role in the repartitioning of dietary energy from adipose tissue to skeletal muscle, thereby promoting fat loss,[121,127] but this hypothesis has yet to be substantiated. Conjugated linoleic acid, which is found in dairy products, has been demonstrated to reduce adipose tissue mass in animals and humans. Possible mechanisms include induction of adipocyte apoptosis and/or differentiation and reduction of triglyceride accumulation in adipocytes.[128]

Bone mineralization. Thirteen observational and intervention studies, with milk or dairy as the exposure and total body or regional BMC in children or adolescents as outcomes of interest, were included in the review (Table S5 in the Supporting Information online). In total, 12 studies showed some evidence of higher regional or total body BMC or greater gains in regional or total body BMC over time in children and adolescents with higher short- or long-term dairy product intakes. Seven of the studies were RCTs conducted in children between the ages of 5 years and 15 years at baseline, with interventions lasting between 10 months and 2 years. In all seven RCTs, there was a significant improvement in BMC in at least one population subset at one or more sites. However, a number of investigators found null results in other regions of interest or subsets of children, with the diversity in study design, study duration, participants' age and sex, baseline dairy product intakes, bone health indicators, and sites measured precluding direct comparison of outcomes. Furthermore, 7 of the 13 studies included only female participants.

No meta-analysis published to date has considered the impact of dairy products or milk specifically (rather than total calcium or dairy calcium intake) on BMC in children. Evidence considered in the present review suggests that milk or dairy may be positively associated with bone mineralization, though results at a particular site of measurement are inconsistent. It is possible that the advantages of dairy consumption are strongest during growth. Children in New Zealand with a history of milk avoidance had significantly lower total body BMC ($P < 0.05$), were shorter ($P < 0.01$), and were more likely to experience prepubertal bone fracture ($P < 0.001$) than age-matched controls.[129,130] Few studies have been undertaken to determine how dairy food intake during growth affects adult bone integrity, though a twofold greater risk of fracture was found in women reporting low milk intake during childhood in NHANES III (1988–1994).[131] Both heritable and environmental factors influence peak bone mineral mass, a primary determinant of bone integrity later in life.[132]

The beneficial effects of dairy products on bone health and bone mass acquisition in children and adolescents have commonly been attributed to 1) the presence of minerals (including calcium and phosphorus) that form the inorganic matrix of bone; 2) vitamin D that regulates serum calcium and phosphate homeostasis[80]; and 3) potassium that indirectly regulates bone turnover.[133] The basic protein fraction of whey, termed "milk basic protein," has been found in some studies – but not others – to decrease markers of bone resorption and to increase markers of bone formation.[134] The glycoprotein lactoferrin, which is abundant in milk, promotes proliferation and differentiation of osteoblast cells and inhibits osteoclast-mediated bone resorption.[135–137]

Dental health. Of the 11 observational studies in children and adolescents included in the review, all found an inverse association between milk and/or dairy product intake and dental caries or decayed, missing, and filled tooth scores in primary and permanent teeth (Table S6 in the Supporting Information online). In several of these studies, consumption of yogurt[138,139] and cheese[140–142] specifically was inversely associated with dental caries. Most studies did not adjust for intake of added sugars, though one study did find a stronger inverse association between milk consumption and caries in high-sucrose-consuming children.[143]

Although no controlled intervention trials have been conducted in children or adolescents, a substantial body of observational evidence suggests a positive association between milk or dairy product intake and dental health. Components of dairy products, including calcium, phosphate, casein, and lipids, have recognized anticariogenic properties.[144,145] In vitro, casein phosphopeptides from yogurt inhibited dental enamel demineralization and promoted remineralization[146]; the amount of casein phosphopeptide is higher in yogurt than in equal-weight portions of cheese and milk.[147] Casein is incorporated into the salivary pellicle and reduces bacterial adherence to teeth.[148]

Other postulated mechanisms by which cheese in particular may prevent the development and progression of dental caries include buffering of plaque acids and delivery of ionizable calcium and phosphate to reduce enamel demineralization and promote remineralization.[149] In adults, cheese consumption restored neutral plaque pH following consumption of a sugary food[150–152] and increased plaque calcium concentration.[153] Although mechanistic studies have not been conducted in children, results of observational studies in adolescents and adults support an inverse association between cheese consumption and dental caries.[149,151,153]

Height. Seventeen observational and intervention studies were included in the review (Table S7 in the Supporting Information online). Fourteen of these studies found a positive association between milk or dairy product consumption and height or linear growth in children and adolescents, while three found no association. In two seminal studies published in the 1920s, English and Scottish children on a "varied and changing diet of the working class" receiving daily portions of milk at school had significantly greater height gains (0.5–0.75 cm) over a 7-month period than children receiving equicaloric biscuits (significance reported as greater than 3 times probable error).[154,155] The other five intervention trials failed to include a control group with an equicaloric dairy substitute, complicating interpretation of results. Of these five trials, four involved females only, two found a significant increase in height or growth in the milk or dairy calcium group compared with controls,[113,156] one found a difference approaching significance in the below-median calcium consumers,[157] and two found no significant differences between groups in the outcome of interest.[65,94] A prospective cohort study that followed premenarcheal girls annually through early adulthood found that dairy protein intake was a significant predictor of peak height velocity and adult height, while animal or vegetable protein was not.[158] The authors hypothesized that dairy protein itself was not the growth-promoting factor in milk but may serve as a marker of other factors in the nonlipid component.

The results of the present review are in agreement with a recently published meta-analysis of 12 intervention studies in both developed and developing countries that concluded that 0.4 cm extra growth per annum was a conservative estimate of the effect of 245 mL of milk supplementation daily, with lower baseline height-for-age (a sign of undernutrition) and peripubertal status increasing the effect of milk supplementation on linear growth.[159] The "milk hypothesis" proposed by Bogin[160] suggests that greater milk consumption during infancy and childhood supports attainment of linear growth potential. This is corroborated to some extent by secular trends in milk consumption and growth in Holland and Japan.[161,162] In children, positive correlations have been demonstrated between milk consumption and circulating concentrations of insulin-like growth factor 1,[65,163,164] a key regulator of growth, though the apparent relationship could reflect an underlying association of insulin-like growth factor 1 with dietary protein.[165] Calcium, though a major component of hydroxyapatite in the bone matrix, has not been associated with height gain in supplementation studies.[157,166]

Blood pressure. Two prospective cohort studies investigating an association between dairy product intake and blood pressure in children met inclusion criteria for the review (Table S8 in the Supporting Information online). Both of these studies found that children with higher dairy intakes early in life (18–59 months) had lower blood pressure in middle childhood[167] or early adolescence.[168]

These results corroborate a much larger body of evidence of an inverse association between dairy product intake and blood pressure in adults.[169] Dairy products are rich in calcium, magnesium, and potassium, nutrients associated with blood pressure management.[170,171] In addition, angiotensin-converting enzyme inhibitory peptide in dairy protein reduces production of angiotensin II, the agent of the renin-angiotensin system causing arteriole constriction.[119]

RESEARCH GAPS

While dairy foods make an important contribution to children's nutrient intake, growth, and health, there remain a number of pertinent knowledge gaps. Few studies have measured biomarkers of nutrient status associated with dairy consumption in children. The impact of insulin-like growth factor 1 elevation secondary to dairy product consumption in childhood requires additional research. Aspects of the metabolic syndrome, which have been inversely associated with dairy intake in animal models and adults,[172] warrant research in children and adolescents. Furthermore, nationally representative data on the adequacy of childhood milk and dairy product consumption are available from few countries globally. A more thorough understanding of the decline in dairy product consumption among children and teenagers is critical for addressing this trend.

Controlled intervention trials taking into consideration pubertal development are needed to isolate the potential association of dairy product intake with linear growth and bone health and to identify means of increasing dairy consumption, especially during critical periods. Long-term prospective cohort studies of dairy consumption and pediatric health outcomes would also add to the knowledge base.

CONCLUSION

Despite the important contribution of dairy products to the diets of children and adolescents, data indicate a secular decline in dairy product consumption and a tendency for decreasing intake with age. Factors that may impact these trends over time and within a population cohort include parental influence, sex, substitution of milk with other beverages, and overall dietary quality.

Dairy products contribute to adequate intakes of micronutrient and macronutrients by children and adolescents in developed countries. Dairy calcium is highly bioavailable and accounts for more than 50% of total calcium intake. In addition, dairy products provide high-quality protein with peptides and bioactive factors that have specific effects on growth. The lipid portion of dairy supplies energy as well as essential and nonessential fatty acids.

Childhood dairy product consumption may affect various facets of growth and development. Despite concerns that energy provided by dairy may contribute to childhood obesity, evidence presented in this review overwhelmingly supports a null or inverse association between milk or dairy product intake and indicators of adiposity. Consumption of dairy products, particularly cheese and yogurt, is associated with reduction of dental caries in children. Results of two prospective cohort studies support an inverse association between dairy intake in early childhood and blood pressure in mid-childhood or early adolescence. Evidence to date suggests that dairy products are important for linear growth and bone health. Additional research, particularly controlled intervention trials and long-term prospective cohort studies, is warranted to better understand how dairy food intake may affect health outcomes in children and adolescents.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article at the publisher's website:

Table S1 **Percent of children and adolescents meeting dairy product intake recommendations.**
Table S2 **Nutrient content[a] of select dairy foods (per 100 g).**
Table S3 **Percent contribution of total dairy products[a] to key nutrient intakes in children and adolescents in developed countries[b].**
Table S4 **Observational and intervention studies of dairy intake and BMI, body fat, or energy balance in children and adolescents.**
Table S5 **Observational and intervention studies of dairy intake and bone health in children and adolescents (total body or regional BMC as outcome of interest).**
Table S6 **Observational and intervention studies of dairy intake and dental health in children and adolescents.**
Table S7 **Observational and intervention studies of dairy intake and height change in children and adolescents.**
Table S8 **Observational and intervention studies of dairy intake and blood pressure in children and adolescents.**