REVIEW ARTICLE

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Milk and Health

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Milk products from cows and other nonhuman mammals are major components of traditional Western diets, especially in cold climates. The recommended intake of milk or equivalent portions of cheese, yogurt, or other dairy products in the United States is three 8-oz (237 ml) servings per day for adults and children 9 years of age or older, an amount that is substantially higher than the current average intake among adults of 1.6 servings per day.[1] The recommended intake amount has been justified to meet nutritional requirements for calcium and reduce the risk of bone fractures. However, the health benefit of a high intake of milk products has not been established, and concerns exist about the risks of possible adverse health outcomes. Therefore, the role of dairy consumption in human nutrition and disease prevention warrants careful assessment.

COMPOSITION OF DAIRY PRODUCTS

Because the natural function of milk is to nourish and promote the growth of young mammals, it contains all essential nutrients as well as multiple anabolic hormones (Table 1).[3-6] To increase milk production, cows have been bred to produce higher levels of insulin-like growth factor I (IGF-I),[7] and they are pregnant for most of the time they are milked,[8] which greatly increases levels of progestins, estrogens, and other hormones in milk.[9]

Milk processing has many potential health implications. Pasteurization reduces transmission of brucellosis, tuberculosis, and other pathogens. Fermentation to produce aged cheese, yogurt, kefir, and other products denatures peptide hormones, alters protein antigens, reduces lactose content, and affects bacterial composition.[10] Fractionation yields butter, reduced-fat products, and whey protein, and fortification with vitamins A and D can supplement diets.

GROWTH AND DEVELOPMENT

If breast milk is not available, cow's milk (as the basis of infant formula for children younger than 1 year of age) can add important nutritional value during early childhood. However, normal growth and development can be obtained throughout childhood without dairy products if attention is given to diet quality,[11] including the use of supplemental B_{12} in diets that include few animal products and vitamin D to compensate for low sun exposure.

Even with adequate overall nutrition, milk consumption augments longitudinal growth and attained height.[12-14] Whether this growth-promoting effect is caused by specific amino acids, anabolic hormones, or other factors is not clear. Cow's milk contains substantial amounts of the branched-chain amino acids leucine, isoleucine, and valine, which are key to protein quality. Consumption of these amino acids by humans increases plasma concentrations of IGF-I, which mediates growth hormone action,[15-20] and leucine specifically activates the mammalian target of rapamycin (mTOR) pathway, which promotes cell replication and inhibits apoptosis.[21] However, the health consequences of accelerated growth and greater adult height are complex. Tall stature is associated with lower risks of cardiovascular disease[22] but with higher risks of many cancers,[23] hip fractures,[24] and pulmonary emboli.[22]

Bone Health and Fracture Risk

A central rationale for high lifelong milk consumption has been to meet calcium requirements for bone health (Table 2).[26] Paradoxically, countries with the highest intakes of milk and calcium tend to have the highest rates of hip fractures (Fig. 1).[30,31] Although this correlation may not be causal and might be due to confounding by factors such as vitamin D status and ethnicity, low dairy consumption is clearly compatible with low rates of hip fracture.

The basis for the U.S. recommendations for milk consumption derives from studies assessing the balance of calcium intake and excretion in just 155 adults in whom the estimated calcium intake needed to maintain balance was 741 mg per day.[25,32] Beyond small size, these balance studies have other serious limitations, including short duration (2 to 3 weeks) and high habitual calcium intakes. By contrast, the estimated balance was attained at approximately 200 mg of dietary calcium per day among Peruvian men with low habitual calcium intake,[33] a finding consistent with the ability of the body to greatly upregulate absorption when dietary calcium is low. In randomized trials that used bone mineral density as a surrogate for fracture risk, calcium supplements of 1000 to 2000 mg per day resulted in 1 to 3% greater bone mineral density than placebo. If sustained, this small divergence could be important. However, after 1 year, the rate of change in bone mineral density among late perimenopausal and postmenopausal women equaled that of placebo[34]; with discontinuation of supplementation, the small difference in bone mineral density is lost.[35] Because of this transient phenomenon, trials lasting 1 year or less can be misleading,[34] and the 2-to-3-week balance studies used to establish calcium requirements have limited relevance to fracture risk.[33] We therefore think that cross-sectional studies can pro-

Table 1. Nutrient Composition of Human and Cow's Milk and Cheese.*

Component	Human Milk	Whole-Fat Cow's Milk	Fat-Free Cow's Milk	Cheddar Cheese†
		(per 237 ml)		
No. of kcal	172	149	83	149
Protein — g	2.5	7.7	8.2	8.4
Total fat — g	10.8	7.9	0.2	12.3
Saturated fat — g	4.9	4.6	0.1	7.0
Carbohydrate — g	16.9	11.7	12.1	1.1
Calcium — mg	78.7	276.0	298.0	262.0
Potassium — mg	125.0	322.0	381.0	28.0
Phosphorus — mg	34.4	205.0	246.0	167.9

* Values are from the U.S. Department of Agriculture.[2]
† The amount of cheese (37 g) is isocaloric with 237 ml of whole milk.

Table 2. Suggested Calcium Intake Amounts, According to the United States, United Kingdom, and World Health Organization, by Age.

Source	Age Group						
	0 to 1 yr	1 to 3 yr	4 to 18 yr		19 to 50 yr	51 to 70 yr	>70 yr
			milligrams per day				
United States*	—	700	1000 (4–8 yr)	1300 (9–18 yr)	1000	1000 (M), 1200 (F)	1200
United Kingdom†	525	350	450 (4–6 yr), 550 (7–10 yr)	1000 (11–18 yr, M), 800 (11–18 yr, F)	700‡	700	
WHO§	—	—	—		500	500	500

* Data are from the Institute of Medicine.[25] F denotes female, and M male.
† Data are from the Committee on Medical Aspects of Food and Nutrition Policy, U.K. Department of Health.[26]
‡ Intake during lactation is recommended to be increased by 550 mg per day.[26]
§ Data are from the World Health Organization (WHO) Report of a Joint WHO/FAO Expert Consultation.[27]

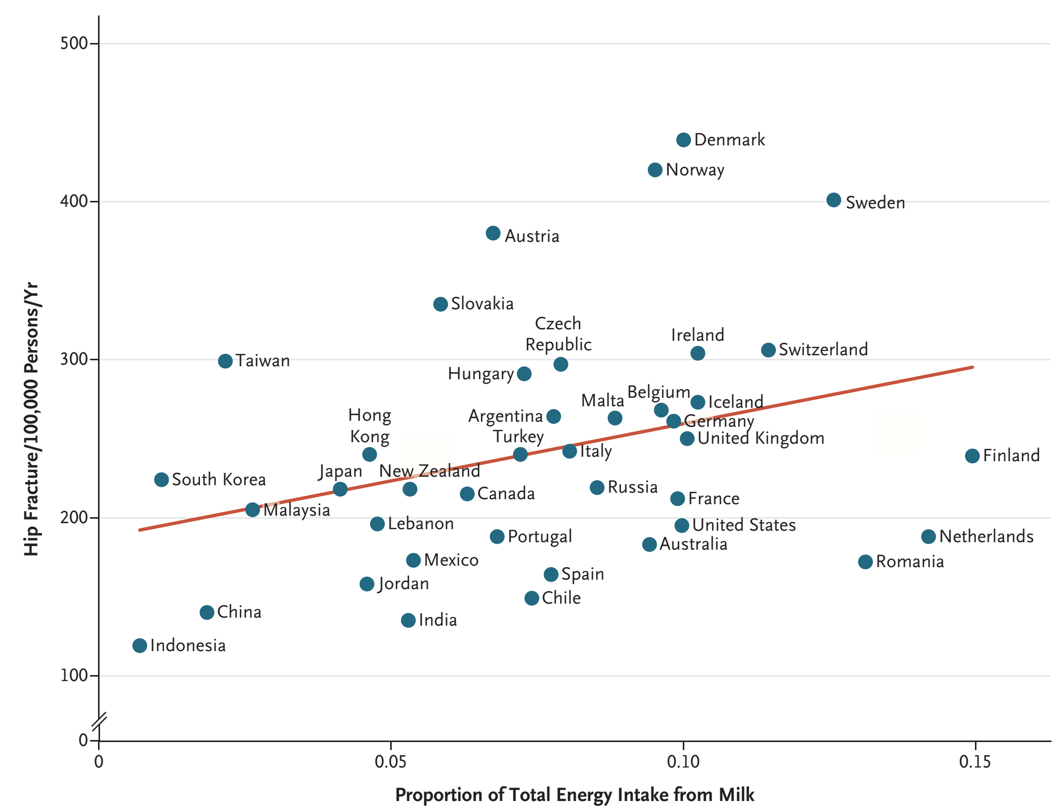

Figure 1. Milk Consumption and Hip Fractures.

Shown are milk consumption (as the proportion of total energy intake) and age-standardized rates of hip fractures per 100,000 persons per year. Data on national milk intake (including all forms of milk, cheese, and other derived products) are from the Food and Agriculture Organization of the United Nations,[28] and nationally representative hip fracture rates, which are for men and women combined, standardized to the 2010 world population, are from Kanis et al.[29]

vide additional useful information on steady-state bone mineral density. Among nearly 10,000 men and women representative of the U.S. population, calcium intake was unrelated to bone mineral density at the hip.[36]

In a meta-analysis of prospective studies, total calcium intakes ranging from less than 555 mg per day to more than 1100 mg per day were unrelated to the risk of hip fracture.[37] In other meta-analyses of prospective studies, milk intake (ranging from fewer than 1.5 servings per week to 30 or more servings per week) or total dairy food consumption was unrelated to the risk of hip fracture in men or women.[38-40] Both positive and inverse associations have been observed in subsequent studies[41,42]; the overall evidence does not support a benefit of higher dairy consumption for prevention of hip fractures.

Clinical trials examining calcium supplements and the risk of fractures are complicated to interpret because most supplements included both calcium and vitamin D; studies of calcium alone are limited in size, number, and duration. In a meta-analysis of five trials in which a total of 6740 patients with a total of 814 nonvertebral fractures received either calcium-only supplements or placebo,[37] no significant benefit from calcium was seen in reducing the number of all nonvertebral fractures (relative risk, 0.92; 95% confidence interval [CI], 0.81 to 1.05), and the risk of hip fracture was greater among persons who received calcium supplements than among those who received placebo (relative risk, 1.64; 95% CI, 1.02 to 2.64).

Estimation of calcium requirements for children is problematic because a positive balance is needed for growth, and recommendations reflect this uncertainty. In the United States, the recommended daily allowance of calcium is 1000 mg per day for children 4 to 8 years of age, whereas in the United Kingdom 450 to 550 mg per day is considered adequate (Table 2). Among girls in the early stages of puberty, calcium balance was positive even with an intake of less than 400 mg per day,[43] and among children 4 to 8 years of age, calcium intake was uncorrelated with bone mineral density.[44] Studies of calcium or dairy supplementation and bone mineral density in children show the same transient phenomenon observed in adults. Although with supplementation a small increase — or no increase — in bone mineral density is observed,[45] increases do not persist after discontinuation,[46-49] thus providing no evidence that high calcium intake is needed during childhood to serve as a "bank" for calcium throughout life. In a randomized trial, consumption of three additional servings of milk or equivalent dairy foods per day for 18 months by girls and boys in early stages of puberty who had calcium intakes below 800 mg per day had no effect on bone mineralization.[50] These findings suggest a fairly low threshold for calcium intake, above which higher intake has little additional effect on bone mineralization. Although concern has been raised about the effects on calcium balance of the high phosphorous content of cow's milk (Table 1), in a large cross-sectional study in the United States, phosphorus intake tended to be positively associated with bone mineral density.[51]

Because milk increases attained height, and taller height is strongly related to fractures of the hip and other bones,[24] high milk consumption during adolescence was examined in relation to the risk of hip fractures later in life in two large cohorts.[52] Among men, milk intake during adolescence was linearly associated with a 9% greater risk of hip fracture later in life for every additional glass consumed per day. No association with the risk of hip fracture was seen among women. Thus, existing data do not support high intakes of milk during adolescence for prevention of fractures later in life and suggest that such intakes may contribute to the high incidence of fractures in countries with the greatest milk consumption.

BODY WEIGHT AND OBESITY

Although milk has been widely promoted as beneficial for weight control, in a meta-analysis of 29 randomized trials, no overall effects of milk or other dairy foods on body weight were seen.[53] Among men and women in three large cohorts,[54] changes in consumption of whole milk, low-fat milk, and cheese had no clear associations with weight change, whereas yogurt consumption was associated with less weight gain. As one of the only commonly consumed sources of probiotics in modern Western diets, freshly fermented dairy products such as yogurt may protect against obesity and confer other health benefits resulting from their effects on the gut microbiome.[55-58] However, confounding by the generally healthier lifestyles of people who consume yogurt cannot be excluded.

Studies of milk consumption and body weight in children are few and are subject to confounding and reverse causation. Among 12,829 adolescents followed for 3 years, intake of low-fat milk was positively associated with gain in body-mass index (BMI, the weight in kilograms divided by the square of the height in meters), but intakes of full-fat milk and dairy fat were not; the weight gain associated with low-fat milk was accounted for by higher energy intake.[59] Similarly, in three cohorts of young children, consumption of full-fat or 2%-fat milk was associated with lower BMI or lower risk of obesity than was consumption of low-fat or skim milk.[60-62] In one study, no overall association between milk and percent body fat was observed.[63]

Few randomized, controlled trials of milk consumption have been conducted among children or adolescents. In a 1976 study in the United Kingdom, 581 elementary-school children living in a low-income area were randomly assigned to receive either school lunch with milk (about 7 oz, presumably of whole milk) or lunch without milk. After 21 months, no significant difference in weight was seen, although children in the group that received milk had modestly increased height.[64] In subsequent smaller, randomized trials published since 2008 that enrolled overweight or normal-weight children, consumption of low-fat milk did not reduce body weight more than consumption of sugar-sweetened beverages, fruit juice, or water.[65-68] In a recent trial designed to examine the effects of dairy calcium, 274 adolescent girls with BMIs ranging from the 50th to the 98th percentile were randomly assigned either to a group that received an intervention that substantially increased their consumption of low-fat dairy products (from 0.6 servings per day to 3.2 servings per day) or to a control group in which consumption was to remain constant (and increased only from 0.6 servings per day to 0.7 servings per day). Contrary to the hypothesis, no effect on amounts of body fat was reported after 1 year.[69]

Overall, the findings of prospective cohort studies and randomized trials do not show clear effects of milk intake on body weight in children or adults. Contrary to U.S. Department of Agriculture (USDA) advice to choose reduced-fat dairy, low-fat milk does not appear to have advantages over whole milk for weight control — and in children, available evidence suggests greater long-term weight gain with reduced-fat milk than with full-fat milk. Regular consumption of yogurt may result in less weight gain, and this possibility warrants further study in appropriately controlled trials to minimize confounding.

BLOOD PRESSURE, LIPIDS, AND CARDIOVASCULAR DISEASE

The relatively high potassium content of milk has led to the suggestion that greater milk intake may reduce blood pressure. The Dietary Approaches to Stop Hypertension (DASH) diet, which includes low-fat dairy foods, reduces blood pressure, but the specific contribution of milk is unclear because the diet is low in sodium and high in fruits and vegetables. Randomized trials of low-fat milk have shown inconsistent results with respect to reduction of blood pressure.[15,70,71] It is important to note that the effect of milk in such trials often depends on the comparison beverages or foods. If milk replaces sugar-sweetened beverages or other refined carbohydrates, outcomes will probably be beneficial,[72,73] but results may differ if milk replaces nuts, legumes, or whole fruits.

Prevailing recommendations also advocate consumption of reduced-fat dairy products instead of full-fat alternatives because saturated fat (about 65% of dairy fats is saturated fat[2]) increases low-density lipoprotein (LDL) cholesterol, and increased LDL cholesterol is an established risk factor for coronary heart disease. However, the reported effects of saturated fat depend on the comparison source of calories.[74] Replacement of saturated fat with most carbohydrates, as encouraged for many years by USDA dietary guidelines, lowers LDL cholesterol; however, high-density lipoprotein (HDL) cholesterol and LDL cholesterol particle sizes also decrease, and levels of triglycerides and inflammatory factors increase.[75,76] Alternatively, replacement of saturated fat with unsaturated fats has similar benefits on LDL cholesterol but without the adverse effects.[76,77]

In prospective cohort studies, neither whole milk nor low-fat milk has been clearly associated with the incidence of, or mortality associated with, coronary heart disease or stroke.[78] As with studies of blood lipids, the association of milk with the risk of cardiovascular disease depends on the comparison foods. In most cohort studies, no specific comparison was made; by default, the comparison was everything else in the diet — typically large amounts of refined grains, potato products, sugar, and meat. In a large cohort of women, full-fat and low-fat dairy products had similar relationships to coronary heart disease risk; both were associated with a lower risk than that associated with same number of servings of red meat but with a higher risk than was seen with the same number of servings of fish or nuts.[79] A similar pattern of risk of stroke was seen among men and women.[80] Likewise, dairy fat per se was associated with a higher risk of cardiovascular disease than was polyunsaturated or vegetable fat.[81] For persons living in low-income countries where diets are very high in starch, moderate intake of dairy foods may reduce cardiovascular disease by providing nutritional value and reducing glycemic load.[82]

DIABETES

Cow's milk has been hypothesized to be a cause of type 1 diabetes owing to cross-reactivity between dairy proteins and pancreatic islet cells.[83] However, in a randomized trial, children weaned to hydrolyzed protein instead of cow's milk did not have fewer autoantibodies to beta cells after 7 years than children who drank cow's milk,[84] and the relationship of milk intake to the risk of type 1 diabetes remains unclear.

Intake of dairy products has been associated with a modestly lower risk of type 2 diabetes in some cohort studies.[85] However, in large meta-analyses, dairy consumption was not associated with[86] — or was only weakly associated with[87] — lower risk. Furthermore, a genetic marker for lactose tolerance, and thus higher milk intake, was not related to diabetes risk.[88] In a substitution analysis, the risk of diabetes was lower with milk consumption than with consumption of sugar-sweetened beverages or fruit juices but higher with milk consumption than with coffee consumption.[89]

CANCER

In international comparisons, consumption of dairy products is strongly correlated with rates of breast cancer, prostate cancer, and other cancers.[9,90] The effects of milk consumption on plasma IGF-I,[20,91] which predicts increased risks of prostate and breast cancers,[92] provides a plausible mechanism. In prospective cohort studies, milk consumption is most consistently associated with a greater risk of prostate cancer,[23,93] especially aggressive or fatal forms, but not with a greater risk of breast cancer.[23] Total dairy intake has been associated with a greater risk of endometrial cancer, particularly among postmenopausal women who are not receiving hormone therapy, a finding possibly related to the sex-hormone content of dairy products.[94] Consumption of dairy products or lactose has been hypothesized to increase the risk of ovarian cancer, but no relation was seen in a pooled analysis.[95] In contrast, in meta-analyses and pooled analyses of primary data,[96,97] milk consumption was inversely associated with the risk of colorectal cancer, potentially owing to its high calcium content.[23] A major limitation of the existing literature is that almost all prospective studies have been initiated among persons in midlife or later, whereas many cancer risk factors operate in childhood or early adult life.[98] In one study of diets in adolescents, milk intake was shown to be unrelated to a future risk of breast cancer.[99]

ALLERGIES AND INTOLERANCE

Allergy to cow's milk proteins may affect up to 4% of infants and cause considerable nutritional problems.[100] Scattered reports suggest that milk consumption may exacerbate atopic tendencies, conferring a predisposition to asthma, eczema, and food allergies.[100,101] Over a period of 10 years, infants with a family history of atopy who were randomly assigned to receive hydrolyzed protein formula had a lower risk of any allergic disease and of eczema than did infants who were randomly assigned to receive cow's milk.[102] In a double-blind crossover study of children with intolerance to cow's milk, 44 of 65 children had a reduction in symptoms (including resolution of anal fissures) when they consumed soy milk, whereas there was no reduction in symptoms among children in the group that received cow's milk.[103] Beyond childhood, cow's milk may precipitate asthmatic exacerbations[104] and related conditions.[105] In addition, lactose intolerance limits consumption of milk worldwide.

TOTAL MORTALITY

In a meta-analysis that included 29 cohort studies, intakes of milk (total, high-fat, and low-fat) or total intakes of dairy foods were not associated with overall mortality.[78] In a recent analysis of three large cohorts with more than 30 years of follow-up, whole milk was associated with higher total mortality, but consumption of low-fat milk and cheese was not.[106] However, when major protein sources were compared, consumption of dairy foods was associated with lower mortality than consumption of processed red meat and eggs, with similar mortality to consumption of unprocessed red meat, poultry, and fish, and with significantly higher mortality than consumption of plant-based sources of protein[107] (Fig. 2).

ORGANIC AND GRASS-FED PRODUCTION

Consumption of organic milk instead of conventionally produced milk has been promoted because of concern about the use of recombinant bovine somatotropin and the presence of residues of pesticides and antibiotics in conventionally produced milk and because of the expectation that organic milk has better nutritional composition. Although milk from cows treated with bovine somatotropin contains elevated IGF-I levels,[108] no long-term studies have compared milk from cows treated with bovine somatotro-

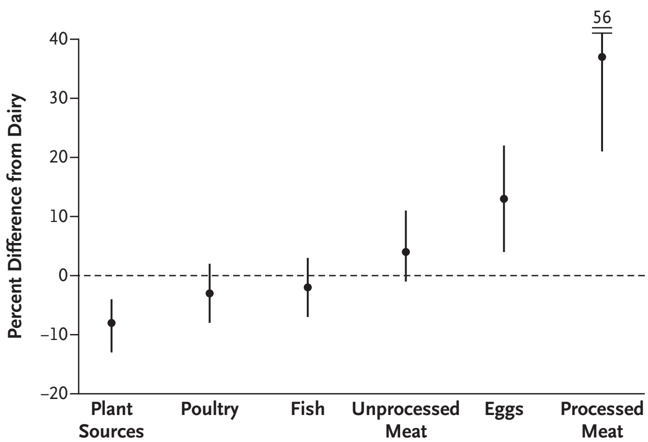

Figure 2. All-Cause Mortality Associated with Protein Sources.

Shown are the percent differences in all-cause mortality between dairy foods and other major protein sources. The dashed line at 0 is the reference value for mortality associated with dairy as a protein source. Comparisons are for 3% of energy from protein from each source; for milk, this corresponds to approximately 500 g or two 8-oz glasses. Data are from Song et al.,[107] recalculated to use dairy foods as the comparison, and are based on up to 32 years of follow-up of 131,342 men and women. Associations are adjusted for major lifestyle, dietary, and other risk factors for cardiovascular disease and cancer.

pin with milk from untreated cows with respect to health outcomes in humans. After extensive reviews, Canada and the European Union banned the sale of milk from cows treated with bovine somatotropin — not because of human health issues, but because of animal welfare issues, including increased mastitis, foot problems, and reduced fertility in treated cows.[108,109]

Organic milk may have slightly higher amounts of n–3 polyunsaturated fatty acids[110] and beta carotene[111] than conventional milk — a consequence of grass-feeding, not of its organic status. The sex-hormone content of milk is increased if cows are milked while they are pregnant, but this practice appears to be widespread among both conventional and organic milk producers.

ENVIRONMENTAL EFFECTS

Foods may influence health both directly and indirectly through the environmental effects of their production.[112] The effects of dairy production, particularly industrial-scale production, on greenhouse gas production and climate change, water use and pollution, and antibiotic resistance are large[113-116] — potentially 5 to 10 times greater per unit of protein than the effects from production of soy foods, other legumes, and most grains.[117] Thus, the environmental implications of doubling production to meet current U.S. dietary guidelines likewise would be large — massive, if applied worldwide, including low-income countries with low intakes of dairy.[118] Conversely, limiting dairy production could make a major contribution toward reaching international greenhouse-gas targets.[119]

CONCLUSIONS

Cow's milk includes a complex combination of macronutrients, micronutrients, and growth-promoting factors that can contribute to human nutrition; however, all these nutrients can be obtained from other sources (as has been the case in many traditional societies with historically low intakes of dairy products). For adults, the overall evidence does not support high dairy consumption for reduction of fractures, which has been a primary justification for current U.S. recommendations. Moreover, total dairy consumption has not been clearly related to weight control or to risks of diabetes and cardiovascular disease. High consumption of dairy foods is likely to increase the risks of prostate cancer and possibly endometrial cancer but reduce the risk of colorectal cancer. It is important to note that the reported health effects of dairy foods depend strongly on the specific foods or beverages to which they are compared; for many outcomes, dairy foods compare favorably with processed red meat or sugar-sweetened beverages but less favorably with plant-protein sources such as nuts. Furthermore, no clear benefit of consuming reduced-fat dairy over whole dairy products has been established.

The effects on children of consumption of cow's milk are less clear because of children's greater nutritional requirements for growth, and data are more limited. If mother's milk is not available, cow's milk may provide a valuable substitute in early childhood. Milk promotes growth velocity and greater attained height, which confer both risks and benefits. The high nutrient density of milk can be particularly beneficial in regions where overall diet quality and energy intake are compromised. However, in populations with generally adequate nutrition, high consumption of milk may increase the risk of fractures later in life, and the association of greater height with the risk of cancer remains a concern.

In our opinion, the current recommendation to greatly increase consumption of dairy foods to 3 or more servings per day does not appear to be justified. The optimal intake of milk for an individual person will depend on overall diet quality. If diet quality is low, especially for children in low-income environments, dairy foods can improve nutrition, whereas if diet quality is high, increased intake is unlikely to provide substantial benefits, and harms are possible. When consumption of milk is low, the two nutrients of primary concern, calcium and vitamin D (which is of particular concern at higher latitudes),[120] can be obtained from other foods or supplements without the potential negative consequences of dairy foods. For calcium, alternative dietary sources include kale, broccoli, tofu, nuts, beans, and fortified orange juice[11,121]; for vitamin D, supplements can provide adequate intake at far lower cost than fortified milk. Pending additional research, guidelines for milk and equivalent dairy foods ideally should designate an acceptable intake (such as 0 to 2 servings per day for adults), deemphasize reduced-fat milk as preferable to whole milk, and discourage consumption of sugar-sweetened dairy foods in populations with high rates of overweight and obesity.

Disclosure forms provided by the authors are available with the full text of this article at NEJM.org.

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