Dairy products, yogurts, and bone health1–3

René Rizzoli

ABSTRACT
Fracture risk is determined by bone mass, geometry, and microstructure, which result from peak bone mass (the amount attained at the end of pubertal growth) and from the amount of bone lost subsequently. Nutritional intakes are an important environmental factor that influence both bone mass accumulation during childhood and adolescence and bone loss that occurs in later life. Bone growth is influenced by dietary intake, particularly of calcium and protein. Adequate dietary calcium and protein are essential to achieve optimal peak bone mass during skeletal growth and to prevent bone loss in the elderly. Dairy products are rich in nutrients that are essential for good bone health, including calcium, protein, vitamin D, phosphorus, and other micronutrients and macronutrients. Studies supporting the beneficial effects of milk or dairy products on bone health show a significant inverse association between dairy food intake and bone turnover markers and a positive association with bone mineral content. Fortified dairy products induce more favorable changes in biochemical indexes of bone metabolism than does calcium supplementation alone. The associations between the consumption of dairy products and the risk of hip fracture are less well established, although yogurt intake shows a weakly positive protective trend for hip fracture. By consuming 3 servings of dairy products per day, the recommended daily intakes of nutrients essential for good bone health may be readily achieved. Dairy products could therefore improve bone health and reduce the risk of fractures in later life. Am J Clin Nutr 2014;99(suppl):1256S–62S.

INTRODUCTION
Bone growth begins with the development of the skeleton during fetal life and continues until the end of the second decade of life when the maturation process is complete and peak bone mass is achieved. In adult life, bone mineral mass is determined by the amount of bone accumulated at the end of skeletal growth (peak bone mass) and by the amount of bone lost subsequently. At any given age, the key determinants of fracture risk, bone mineral mass, and bone structure result from the difference between the amounts of bone gained and lost (1, 2).

Whereas bone mineral mass gain during childhood and adolescence is influenced by many factors, the major determinants of peak bone mass and strength are genetic (accounting for 60–80% of the variance). The remaining factors may be amenable to positive intervention, including nutrition, particularly the intake of calcium and protein, physical activity, and exposure to a variety of risk factors (1, 2).

The role of calcium intake in influencing bone mineral mass is well recognized (3). An adequate calcium intake increases bone mineral density (BMD)4 during skeletal growth and prevents bone loss and osteoporotic fractures in the elderly (1). The greatest amount of dietary calcium is obtained from milk and dairy foods, which also provide the human diet with vitamin D (when dairy products are fortified), protein, phosphorus, potassium, and other macro- and micro-nutrients important for bone health (3).

CALCIUM AND PROTEIN AS MAJOR CONSTITUENTS OF DAIRY PRODUCTS
Dairy products may represent the best dietary sources of calcium because of the high content, high absorptive rate, and relatively low cost (4). Moreover, dairy products provide more protein, calcium, magnesium, potassium, zinc, and phosphorus per calorie than any other food (Table 1) (3, 6). For example, 250 mg of calcium may be obtained from a 200-mL glass of milk, a 180-g serving of yogurt, or 30 g of hard cheese. The consumption of 3–4 dairy servings/d would allow one to reach the Recommended Daily Intake (RDI) of calcium (7). Whereas a single dairy serving can deliver 250 mg of calcium, to attain an equivalent amount from other dietary sources would require 5–6 servings of vegetables (dark-green leafy vegetables or legumes) or 10–12 servings of whole-grain or refined-grain foods (8). Thus, dairy products are an efficient source of bone nutrients. Dairy products may represent up to 52–65% of the RDI of calcium and 20–28% of the protein requirement (9–13).

EFFECT OF CALCIUM ON BONE GROWTH
The advantages of dairy consumption to bone health are important during growth. The supplementation of pregnant mothers with calcium and other micronutrients is associated with

1From the Division of Bone Diseases, Geneva University Hospitals and Faculty of Medicine, Geneva, Switzerland.
2Presented at the satellite symposium “First Global Summit on the Health Effects of Yogurt,” held in Boston, MA, at ASN’s Scientific Sessions at Experimental Biology 2013, 24 April 2013. The conference was organized by the ASN, the Nutrition Society, Danone Institute International, and the Dairy Research Institute. The supplement scientific guest editors were Sharon M Donovan, University of Illinois, Urbana, IL, and Raanan Shamir, Schneider Children’s Medical Center and Tel Aviv University, Israel.
3Address correspondence and reprint requests to R Rizzoli, Division of Bone Diseases, Department of Internal Medicine Specialties, Geneva University Hospitals and Faculty of Medicine, 1211 Geneva 14, Switzerland. E-mail: rene.rizzoli@unige.ch.
4Abbreviations used: BMC, bone mineral content; BMD, bone mineral density; FMP, fermented milk product; IGF-I, insulin-like growth factor I; RDA, Recommended Dietary Allowance; RDI, Recommended Daily Intake.
increased skeletal growth and bone mass/density in the offspring. In one study, children born to women who had a higher frequency of intake of calcium-rich foods during pregnancy (milk, milk products, pulses, nonvegetarian foods, green leafy vegetables, and fruit) had higher total and spine bone mineral content (BMC) and BMD at the age of 6 y (14). In a further study, dietary patterns consistent with advice for healthy eating during pregnancy (high in fruit, vegetables, pasta, yogurt, cheese) were associated with greater bone size and BMD in the offspring at 9 y of age (15).

The beneficial effects of calcium and dairy products on bone mineral mass during growth have been confirmed from meta-analyses of numerous clinical studies on calcium supplementation and increased dietary dairy products in children (16, 17). A positive effect of calcium supplementation was shown on total body BMC and upper limb BMD with daily doses of calcium ranging between 300 and 1200 mg/d in children aged 3–18 y (16). Increased intakes of dietary calcium/dairy products were associated with increases in total-body and lumbar spine BMC in children with low baseline intakes (17). In studies of calcium supplementation for >12 mo, calcium-enriched foods significantly increased bone mass accrual in prepubertal girls and boys (18, 19), and the effect was maintained for 1–3 y after discontinuation of calcium supplementation (19, 20).

Recommended Dietary Allowances (RDAs) of calcium provided by the Institute of Medicine for the North American population range from 700 to 1300 mg/d, depending on age (eg, 1000 mg/d for 4- to 8-y-olds and 1300 mg/d for 9- to 18-y-olds (21)). Recommendations are not consistent worldwide, and in the European Union the current RDI for calcium is 800 mg/d (22). Nonetheless, calcium intakes do not meet RDIs in many countries. In the United States, mean calcium intake was lowest among teenage girls, at ~900 mg/d (23). Among European girls, the mean calcium intake varied between 600 mg/d in Italy and 1250 mg/d in Finland (24). In France, where the RDI for calcium is 1200 mg/d for adolescents, 63–73% of girls aged 11–17 y consumed less than two-thirds of the RDI (25).

EFFECT OF PROTEIN ON BONE GROWTH

Dietary protein provides the body with the necessary amino acids for building the bone matrix. In addition, dietary protein stimulates the osteotropic hormone insulin-like growth factor I (IGF-I), which is important for bone formation (26). Protein intake in children and adolescents influences bone growth and bone mass accumulation. In well-nourished children and adolescents it appears that variations in protein intake within the “normal” range (~0.8–1.5 g · kg body weight\(^{-1} \cdot \text{d}^{-1}\)) can affect skeletal growth and thereby modulate the genetic potential for peak bone mass attainment (2, 27). Spontaneous protein intake correlates positively with BMD and BMC as measured in prepubertal boys (11). In a prospective longitudinal study in healthy boys and girls aged 6–18 y, dietary intakes were recorded over 4 y by using yearly administration of 3-d dietary diaries (28). Bone mass and size were measured at the radius diaphysis by peripheral computerized tomography, and a significant positive association was found between long-term protein intake and peristeal circumferences, cortical area, BMC, and a calculated strength strain index. The mean protein intake was relatively high at ~2 kg · kg body weight\(^{-1} \cdot \text{d}^{-1}\) in prepubertal children and ~1.5 kg · kg body weight\(^{-1} \cdot \text{d}^{-1}\) in pubertal individuals. Overall protein intake accounted for 3–4% of the variance in bone variables. In this study, no association was found with the intake of calcium or sulfur-containing amino acids (28).

EFFECTS OF DAIRY PRODUCTS ON BONE GROWTH

As well as calcium, phosphorus, and vitamins, 1 L of milk provides ~32–35 g of protein, mostly casein, but also whey proteins, which contain growth-promoting elements (2). In growing children, long-term milk avoidance is associated with smaller stature and lower bone mineral mass. Low milk intake during childhood and/or adolescence increases the risk of fracture before puberty. In children who had avoided drinking cow milk for prolonged periods, fracture risk was 2.7-fold higher than in a matched birth cohort (29, 30).

The earliest controlled studies of milk intervention were conducted in British schoolchildren in the 1920s (31, 32). The consumption of 400–600 mL milk/d had a positive effect on height gain over a 7-mo period. Since then, numerous observational studies (Table 2) and randomized controlled trials (Table 3) have shown a favorable influence of dairy products on bone health during childhood and adolescence.

In one intervention trial, the effect of milk supplementation on total-body bone mineral acquisition in adolescent girls was evaluated. The intervention group who received 1 pint/d of milk (whole or reduced fat) for 18 mo had significantly greater increases of areal BMD/BMC and significantly higher concentrations of serum IGF-I than the control group (39). In another study in girls aged 10–12 y who had low dietary calcium intake at inclusion, increasing dietary calcium intake by consuming cheese was more beneficial for cortical bone mineral mass accrual than calcium supplementation in tablet form for the same calcium intake (1000 mg/d) (41). The largest randomized controlled intervention trial with dairy products was conducted in

### Table 1

<table>
<thead>
<tr>
<th>Dairy food (food code)</th>
<th>Calcium (mg)</th>
<th>Potassium (mg)</th>
<th>Phosphorus (mg)</th>
<th>Protein (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk, full-fat 3.7% (01078)</td>
<td>119</td>
<td>151</td>
<td>93</td>
<td>3.3</td>
</tr>
<tr>
<td>Milk, skimmed (01151)</td>
<td>122</td>
<td>156</td>
<td>101</td>
<td>3.4</td>
</tr>
<tr>
<td>Yogurt, plain low-fat (01117)</td>
<td>183</td>
<td>234</td>
<td>144</td>
<td>5.3</td>
</tr>
<tr>
<td>Yogurt, fruit low-fat (01122)</td>
<td>169</td>
<td>216</td>
<td>133</td>
<td>4.9</td>
</tr>
<tr>
<td>Cheddar cheese (01009)</td>
<td>721</td>
<td>98</td>
<td>512</td>
<td>24.9</td>
</tr>
<tr>
<td>Cottage cheese, nonfat (01014)</td>
<td>86</td>
<td>137</td>
<td>190</td>
<td>10.3</td>
</tr>
<tr>
<td>Ice cream, soft-serve, chocolate (01236)</td>
<td>131</td>
<td>177</td>
<td>116</td>
<td>4.1</td>
</tr>
</tbody>
</table>

*Data are from the USDA National Nutrient Database for Standard Reference, release 26 (5).*
10- and 11-y-old Chinese girls. Significantly higher gains in height, body weight, BMC, and areal BMD were observed in the groups receiving milk on school days for 2 y (330 mL milk/d fortified with calcium with or without vitamin D supplementation) compared with the control group (42). Consequently, in the Dietary Guidelines for Americans, the USDA recommends daily milk intakes of 480 mL/d among children aged 2–8 y and 730 mL milk or equivalent dairy products/d among children aged 9 y (7).

PROTEINS AND BONE AND MUSCLE DURING AGING
Dietary protein clearly has a role in bone health, and protein is a modifiable factor in osteoporosis prevention. Protein undernutrition is frequently seen in the elderly and contributes to the development of osteoporosis. In an elderly population, studies have reported a positive relation between protein intake and lean mass and BMD. Whereas the RDA for protein is 0.8 g/kg body weight for adults (6), mean protein intake to reach a neutral nitrogen balance in elderly hospitalized patients was found to be ~1.06 ± 0.28 g/kg/d (5). Higher intakes of protein are recommended for healthy elderly people (36, 48). In another study, median dietary protein intake of 1.1 g/kg body weight among elderly individuals was associated with a higher level of maintenance of lean mass over 3 y of follow-up compared with lower dietary protein intakes (49). Studies in younger women have shown that the consumption of high-quality dairy protein after resistance exercise supports muscle anabolism (50, 51). Milk/dairy consumption after resistance exercise has been shown to positively affect body composition in women by promoting losses in fat, gains or maintenance of lean mass, and preservation of bone. In addition, importantly for bone health, resistance exercise plus dairy products improved BMD at clinically important sites and reduced bone resorption (50, 51).

Approximately 2% (1–8%) of the variance in BMD/BMC may be explained by dietary protein intake. A small positive effect of protein supplementation on lumbar spine BMD has been found in randomized placebo-controlled trials (52). There is some evidence for an effect of dietary protein intake on bone fracture risk. In an observational study conducted over 3 y, representing more than 100,000 person-years, hip fracture risk was inversely related to protein intake, with recent hip fracture showed a positive association between protein intake and diaphyseal bone stability and strength; increased BMC.

A number of controlled intervention trials have been conducted in adults testing the effects of dairy products (milk, cheese, fortified dairy) on markers of bone activity. IGF-I is an essential factor for longitudinal bone growth. IGF-I can also exert anabolic effects on bone mass during adulthood. The consumption of a vitamin D and calcium-fortified soft cheese by healthy postmenopausal women increased protein intake, reduced the serum concentrations of bone resorption biomarkers (i.e., bone-specific carboxy-terminal cross-linked telopeptide of type I collagen (CTX), tartrate-resistant acid phosphatase isoenzyme 5b (TRAP 5b), and collagen type I N-terminal propeptide), and increased serum IGF-I, which is compatible with a neutral nitrogen balance (59). Similar findings were found in studies in elderly women (36, 60).
Intakes of aromatic amino acids, which are particularly prevalent in dairy foods, increase IGF-I and stimulate the intestinal absorption of calcium (67). Serum IGF-I concentrations are increased with protein supplementation in elderly frail individuals, which is accelerated by the addition of zinc supplementation (68). Furthermore, in women with a recent hip fracture, protein supplementation achieves peak increases in IGF-I concentration after only 7 d of treatment (69).

**DAIRY PRODUCTS AND BONE HEALTH**

Observational studies and controlled trials show a significantly positive association between dairy food intake, bone turnover markers, and BMC or BMD (Table 3) (51, 59, 62, 65). The application of an intervention approach combining nutrition, education, and consumption of fortified dairy products for 12 mo induced more favorable changes in biochemical indexes of bone metabolism, such as increased IGF-I, than did calcium supplementation alone among postmenopausal women. The dairy intervention group had greater improvements in pelvis, total-spine, and total-body BMD than did both the calcium supplementation and control groups (64, 70).

BMD or BMC is a surrogate marker for bone strength, whereas the incidence of fracture is the key functional outcome measure. Data on the relation between dairy food intake and fracture risk are limited, and this relation requires further studies. The associations between dairy product consumption, BMD, and hip fracture risk were examined in a 12-y follow-up of the

<table>
<thead>
<tr>
<th>First author, year (reference)</th>
<th>Subjects</th>
<th>Age</th>
<th>Sex</th>
<th>Duration</th>
<th>Type of dairy</th>
<th>Skeletal site</th>
<th>Difference between intervention and control groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cadogan, 1997 (39)</td>
<td>82</td>
<td>12</td>
<td>F</td>
<td>18</td>
<td>Milk (568 mL)</td>
<td>Whole-body</td>
<td>2.9</td>
</tr>
<tr>
<td>Chan, 1995 (40)</td>
<td>48</td>
<td>11</td>
<td>F</td>
<td>12</td>
<td>Dairy</td>
<td>Spine/whole-body</td>
<td>9.9/6.6</td>
</tr>
<tr>
<td>Cheng, 2005 (41)</td>
<td>195</td>
<td>11</td>
<td>F</td>
<td>24</td>
<td>Cheese (= 1000 mg Ca)</td>
<td>Tibia shaft</td>
<td>4.4</td>
</tr>
<tr>
<td>Du, 2004 (42)</td>
<td>757</td>
<td>10</td>
<td>F</td>
<td>24</td>
<td>Milk (330 mL)</td>
<td>Whole-body</td>
<td>4.2</td>
</tr>
<tr>
<td>Gibbons, 2004 (43)</td>
<td>154</td>
<td>14–16</td>
<td>F/M</td>
<td>18</td>
<td>Fortified dairy drink</td>
<td>Whole-body/hip/spine</td>
<td>NSD</td>
</tr>
<tr>
<td>Ho, 2005 (44)</td>
<td>199</td>
<td>14-16</td>
<td>F</td>
<td>12</td>
<td>Fortified soy drink (375 mL)</td>
<td>Spine/hip</td>
<td>NSD</td>
</tr>
<tr>
<td>Lau, 2004 (45)</td>
<td>344</td>
<td>10</td>
<td>F/M</td>
<td>18</td>
<td>Milk powder (= 650 mg Ca)</td>
<td>Spine/hip</td>
<td>1.4/1.1</td>
</tr>
<tr>
<td>Merrilees, 2000 (46)</td>
<td>91</td>
<td>16</td>
<td>F</td>
<td>24</td>
<td>Milk (= 1160 mg Ca)</td>
<td>Spine/femoral neck/trochanter</td>
<td>1.5/4.8/4.8</td>
</tr>
<tr>
<td>Zhu, 2005 (47)</td>
<td>606</td>
<td>10</td>
<td>F</td>
<td>24</td>
<td>Milk (330 mL)</td>
<td>Metacarpal cortical thickness, perioseal diameter</td>
<td>5.7/1.2</td>
</tr>
</tbody>
</table>

1 BMC, bone mineral content; BMD, bone mineral density; NSD, no significant difference.
2 BMC and BMD were assessed by X-ray, dual-energy X-ray absorptiometry, or peripheral quantitative computed tomography.

### TABLE 3

<table>
<thead>
<tr>
<th>First author, year (reference)</th>
<th>Subjects</th>
<th>Age</th>
<th>Sex</th>
<th>Duration</th>
<th>Type of dairy</th>
<th>Skeletal site</th>
<th>Difference between intervention and control groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adolphi, 2009 (56)</td>
<td>85</td>
<td>58.7 ± 0.3²</td>
<td>F</td>
<td>0.5</td>
<td>Fortified fermented milk (175 mL)</td>
<td>Reduction in nocturnal deoxypyridinoline excretion</td>
<td></td>
</tr>
<tr>
<td>Bonjour, 2008 (57)</td>
<td>30</td>
<td>59.3 ± 0.3</td>
<td>F</td>
<td>1.5</td>
<td>Milk</td>
<td>Reduction in PTH, CTX, PINP, osteocalcin</td>
<td></td>
</tr>
<tr>
<td>Bonjour, 2009 (58)</td>
<td>37</td>
<td>84.8 ± 8.1</td>
<td>F</td>
<td>1</td>
<td>Skimmed soft cheese, 2 servings/d</td>
<td>Reduction in PTH, CTX, TRAP 5b; increase in IGF-I, 25(OH)D</td>
<td></td>
</tr>
<tr>
<td>Bonjour, 2012 (59)</td>
<td>71</td>
<td>56.6 ± 3.0</td>
<td>F</td>
<td>1.5</td>
<td>Skimmed soft cheese, 2 servings (100 g/d)</td>
<td>Reduction in PTH, CTX, TRAP 5b; increase in IGF-I</td>
<td></td>
</tr>
<tr>
<td>Bonjour, 2013 (60)</td>
<td>89</td>
<td>85.5</td>
<td>F</td>
<td>2</td>
<td>Either vitamin D– and calcium-fortified yogurt (2 × 125 g/d) (vitamin D 10 µg/d and calcium 800 mg/d) or nonfortified control yogurt providing calcium of 280 mg/d</td>
<td>Reduction in PTH, CTX, TRAP 5b</td>
<td></td>
</tr>
<tr>
<td>Josse, 2010 (51)</td>
<td>20</td>
<td>22.4 ± 2.4</td>
<td>F</td>
<td>3</td>
<td>Milk (2 × 500 mL/d)</td>
<td>Reduction in PTH, CTX</td>
<td></td>
</tr>
<tr>
<td>Kruger, 2006 (61)</td>
<td>82</td>
<td>20–35</td>
<td>F</td>
<td>4</td>
<td>Fortified milk</td>
<td>Reduction in CTX</td>
<td></td>
</tr>
<tr>
<td>Kruger, 2010 (62)</td>
<td>1898</td>
<td>&gt;55</td>
<td>F</td>
<td>4</td>
<td>Fortified milk</td>
<td>Reduction in PTH, CTX, PINP, osteocalcin</td>
<td></td>
</tr>
<tr>
<td>Kruger, 2012 (63)</td>
<td>63</td>
<td>&gt;55</td>
<td>F</td>
<td>3</td>
<td>Fortified milk</td>
<td>Reduction in CTX</td>
<td></td>
</tr>
<tr>
<td>Manios, 2007 (64)</td>
<td>101</td>
<td>60.5 ± 0.7</td>
<td>F</td>
<td>12</td>
<td>Fortified milk and yogurt, 3 servings/d</td>
<td>Reduction in PTH, CTX; increase in BMD</td>
<td></td>
</tr>
<tr>
<td>Thorpe, 2008 (65)</td>
<td>130</td>
<td>45.6 ± 8.9</td>
<td>F/M</td>
<td>12</td>
<td>High-protein dairy</td>
<td>Attenuated bone loss</td>
<td></td>
</tr>
</tbody>
</table>

1 BMD, bone mineral density; CTX, cross-linked teleopeptide of type 1 collagen; IGF-I, insulin-like growth factor I; PINP, procollagen type I N-propeptide; PTH, parathyroid hormone; TRAP 5b, tartrate-resistant acid phosphatase isofrom 5b; 25(OH)D, 25-hydroxyvitamin D.
2 Mean ± SD (all such values).
Dietary galactooligosaccharide supplementation increased bone properties in growing rats through gut fermentation. Preclinical studies have shown that dietary galactooligosaccharide (GOS) supplementation improves mineral absorption with galactooligosaccharide supplementation results in a biologically significant increment in bone mineral accrual (67). Whether a small increase in fractional calcium absorption was greatest after 24 h, consistent with lower gut pH and reduced lactose content.

The large intestine possesses an efficacious vitamin D-dependent calcium absorptive capacity, although dietary calcium is generally in a poorly absorbable form when it reaches the large intestine (73). Various dietary sugars are known to stimulate intestinal calcium absorption by a mechanism that is still poorly understood. Of those, lactitol has a positive effect on the absorption of calcium in the large intestine and on the retention of calcium in the body, as shown in animal models, possibly by reducing the pH of the large intestine content, thereby making calcium more readily absorbable (74). In a small study in 12 postmenopausal women, lactulose consumption (5 or 10 g/d) was shown to increase calcium absorption in a dose-response manner (75).

Prebiotic agents, such as galactooligosaccharides, have been shown to increase calcium absorption in postmenopausal women (76). Adolescence is a time of rapid growth, which represents an opportunity to influence peak bone mass. In male adolescents, the consumption of 15 g oligofructose/d was shown to stimulate fractional calcium absorption (77). Among healthy adolescent girls aged 10–13 y who consumed smoothie drinks twice daily with 0, 2–5, or 5 g galactooligosaccharides for 3-wk periods, improvements in fractional calcium absorption were seen with both 5- and 10-g/d doses of galactooligosaccharides compared with the control (0.444, 0.419, and 0.393, respectively), although a dose-response relation was not observed. The increase in absorption was greatest after 24 h, consistent with lower gut absorption (78). Whether a small increase in fractional calcium absorption with galactooligosaccharide supplementation results in a biologically significant increment in bone mineral accrual leading to higher peak bone mass in the long term remains to be shown. Preclinical studies have shown that dietary galactooligosaccharide supplementation improves mineral absorption and bone properties in growing rats through gut fermentation (79). Dietary galactooligosaccharide supplementation increased femur 45Ca uptake, calcium retention, femur and tibia breaking strength, distal femur total and trabecular volumetric BMD, and area and proximal tibia volumetric BMD in the rats ($P < 0.02$) (79). However, there is currently no direct evidence in humans to show that the observed increase in intestinal calcium absorption through gut-enhanced absorptive activity translates to a significant inhibition of bone resorption and either increased bone accumulation during growth or reduced bone loss in adulthood.

Other studies are investigating how probiotic bacterial strains affect the human gut microbiota and host. Fecal bifidobacteria were shown to increase with galactooligosaccharide treatment, which suggests that calcium absorption may be mediated by the gut microbiota, specifically by bifidobacteria (78, 80). Preliminary studies have investigated the effect of fermented milk products (FMPs) on the human gut microbiome in adult monzygotic female twins, although the changes in microbiome expression observed in gnotobiotic mice fed the same FMP bacterial species were not observed in the human study (81). Future studies may elucidate the direct effects of consuming yogurts and foods containing bacterial species with potential health benefits on the gut microbiomes of various human populations, and consequently on various aspects of human health.

**COST-EFFECTIVENESS OF DAIRY PRODUCTS**

The economic impact of improving dairy product consumption has been estimated in some models (82, 83). By increasing the intake of dairy foods to the recommended 3–4 servings/d, a reduction of at least 20% in osteoporosis-related health care costs could be achieved in the United States, translating to savings of $3.5 billion/y (82). The potential economic impact of increased dairy consumption on osteoporotic fractures has been quantified for selected European countries, such as the Netherlands, France, and Sweden (83). The potential savings on the cost of treating hip fractures exceeded the costs of extra dairy foods in all 3 countries: daily costs of additional dairy products, derived from local market prices, were small and were calculated at €0.44, €0.64, and €0.68 for the Netherlands, France, and Sweden, respectively. The total potential savings on the costs of treating hip fractures were large: ~€129 million for France, €34 million for Sweden, and €6 million for the Netherlands (83).

**CONCLUSIONS**

At all ages, calcium and protein play a key role in bone health, with particular emphasis on the phase of bone growth during childhood and adolescence and in the preservation of bone strength and prevention of osteoporosis in the elderly. Milk and dairy products are an optimal source of calcium as well as other nutrients (eg, potassium and magnesium) with important effects on bone health. Increasing daily calcium and protein intake with dairy products has the potential to improve and sustain bone health and to protect against fractures during childhood, adolescence, and later in life. A significant positive association between dairy food intake and bone turnover markers, BMC, and BMD has been shown in clinical studies. Data on the relation between dairy food intake and fracture risk are limited, and this relation requires further studies. The specific actions of FMPs are under investigation and have yielded some interesting results to date; the elucidation of the mechanisms involved may lead to a greater understanding of the health benefits of dairy products.
REFERENCES


