17 Dairy Milk
A Functional Beverage for Human Health

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17.1 INTRODUCTION

Dairy milk and milk-derived products have been consumed by humans for thousands of years as a dietary staple of many civilizations. Milk was considered so fundamental for ancient Egyptians that its hieroglyph translates to the English verb “to make.” Milk is regarded as one of the most nutritious foods in the food supply, consistent with it containing carbohydrate (mainly as lactose), proteins, lipids, and essential micronutrients. Milk is consumed globally, but its consumption rates differ considerably among regions, with greater intakes among central European and Scandinavian countries, whereas consumption in Asian countries is relatively lower. In Western populations, milk consumption is greatest during early childhood, but intakes decline into adulthood, which may be explained by age-related increases in the onset of lactose intolerance. Advances in milk processing (e.g., pasteurization, homogenization) reduce foodborne illnesses and extend shelf life. Furthermore, improved separation of milk components has facilitated the formulation of novel milk-based beverages and milk-derived products. Milk consumption has been touted for its role in human nutrition, especially for benefits on skeletal and cardiometabolic health. This chapter will therefore discuss the role of milk as a functional food in relation to these health aspects.
17.2 DAIRY MILK COMPOSITION

17.2.1 MACRONUTRIENTS

Commercially available milk that has undergone food processing is the primary form of milk consumed in the food supply. Processed dairy milk contains \( \sim 8 \) g of protein per serving (236 mL; Table 17.1) with protein constituting 3.5% of the total content of fluid milk.\(^5\) Dairy proteins consist primarily of casein (80%) and whey (20%).\(^6\) Casein is further segregated to include \( \alpha-, \beta-, \gamma-, \) and \( \kappa- \) caseins, whereas whey protein contains \( \alpha- \) and \( \beta- \) lactoglobulin, albumin, lactoferrin, and immunoglobulins, growth factors, and enzymes (Table 17.2).\(^6\) In milk, the casein proteins aggregate to form “casein micelles.”\(^6\) In this regard, \( \alpha- \) and \( \beta- \) caseins stabilize calcium phosphate

### TABLE 17.1
Energy and Nutrient Composition of Fluid Dairy Milk

<table>
<thead>
<tr>
<th>Component</th>
<th>Content(^{ab})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (kcal)</td>
<td>90–149</td>
</tr>
<tr>
<td>Macronutrients</td>
<td></td>
</tr>
<tr>
<td>Carbohydrate (g)</td>
<td>12.1–12.4</td>
</tr>
<tr>
<td>Protein (g)</td>
<td>7.7–8.7</td>
</tr>
<tr>
<td>Fat (g)</td>
<td>0.6–7.9</td>
</tr>
<tr>
<td>Minerals</td>
<td></td>
</tr>
<tr>
<td>Calcium (mg)</td>
<td>276–315</td>
</tr>
<tr>
<td>Copper (mg)</td>
<td>0.02–0.06</td>
</tr>
<tr>
<td>Iron (mg)</td>
<td>0.05–0.12</td>
</tr>
<tr>
<td>Magnesium (mg)</td>
<td>24–37</td>
</tr>
<tr>
<td>Phosphorus (mg)</td>
<td>205–254</td>
</tr>
<tr>
<td>Potassium (mg)</td>
<td>322–417</td>
</tr>
<tr>
<td>Selenium (( \mu )g)</td>
<td>5–29</td>
</tr>
<tr>
<td>Sodium (mg)</td>
<td>105–129</td>
</tr>
<tr>
<td>Zinc (mg)</td>
<td>0.90–1.17</td>
</tr>
<tr>
<td>Vitamins</td>
<td></td>
</tr>
<tr>
<td>Vitamin C (mg)</td>
<td>0.5–2.4</td>
</tr>
<tr>
<td>Thiamin (mg)</td>
<td>0.05–0.11</td>
</tr>
<tr>
<td>Riboflavin (mg)</td>
<td>0.41–0.45</td>
</tr>
<tr>
<td>Niacin (mg)</td>
<td>0.21–0.22</td>
</tr>
<tr>
<td>Vitamin B(_6) (mg)</td>
<td>0.09–0.11</td>
</tr>
<tr>
<td>Folate (( \mu )g)</td>
<td>12</td>
</tr>
<tr>
<td>Vitamin B(_12) (( \mu )g)</td>
<td>0.93–1.29</td>
</tr>
<tr>
<td>Vitamin A (IU)</td>
<td>395–522</td>
</tr>
<tr>
<td>Vitamin D (IU)</td>
<td>117–124</td>
</tr>
<tr>
<td>Vitamin E (mg)</td>
<td>0.02–0.17</td>
</tr>
</tbody>
</table>

\(^a\) The range depicts the nutrient content per 1 cup serving (236 mL) across common milk varieties including fat-free milk, low-fat milk, reduced-fat milk, and whole milk.

within the micelle, whereas $\kappa$-caseins on the surface maintain casein aggregates in a colloidal state to prevent precipitation due to their instability at the pH (6.6) of milk. This casein micelle structure helps to maintain a fluid solution of calcium and phosphate that can be delivered to offspring to promote tooth and bone development. Casein micelles also coagulate when they interact with the acidic environment of the stomach. This delays gastric emptying into the small intestine, thereby maximizing the opportunity for protein digestion to occur.\(^6\) Whey proteins are soluble in water and exert antimicrobial, immunomodulatory, anticarcinogenic, and antioxidative properties.\(^6\)

Milk fat represents $\sim$4.2% of the content in raw milk in contrast to processed whole milk that is standardized to 3.25% milk fat. Dairy milk fat contains a complex mixture of nearly 400 unique fatty acids.\(^7\) The predominant factors that determine milk lipid composition are the diet and microbial populations in the rumen of the cow. Bovine milk lipids exist primarily in the form of the milk fat globule membrane (MFGM), with the lipid portion making up 30% of the MFGM.\(^7\) This lipid portion contains phospholipids (25%), cerebrosides (3%), and cholesterol (2%).\(^7\) Milk fat exists primarily as triglycerides ($\sim$98%) with the remaining 2% as diacylglycerol, phospholipids, cholesterol, and free fatty acids.\(^7\)

Approximately two-thirds of milk fat is saturated fat, with palmitic (30%), myristic (11%), and stearic (12%) acids predominating.\(^7\) Short chain fatty acids comprise 11% of the saturated fatty acid content, with butyric (4.4%) and caproic (2.4%) being the most abundant.\(^7\) The remaining third of milk fat consists of mono- and poly-unsaturated fatty acids as well as trans-fatty acids. Oleic acid (18:1; 24%–35%) is the most abundant monounsaturated fatty acid, whereas linoleic acid (18:2; 1.6%) and $\alpha$-linolenic acids (18:3; 0.7%) are the predominant polyunsaturated fatty acids and represent 2.3% of the total fatty acid content.\(^7\) The main trans-fatty acid in milk is vaccenic acid (2.7%).\(^7\) Linoleic acid also exists as several conjugated isomers that are referred to as conjugated linoleic acid (CLA; 0.34%–1.37%). Indeed, dairy products contribute up to 70% of the total CLA that is consumed daily.\(^7\) Milk fat also contains bioactive phospholipids and glycosphingolipids that regulate cell signaling, differentiation and proliferation, and immunity.\(^7\)

### TABLE 17.2

Constituents of Bovine Whey and Casein Proteins

<table>
<thead>
<tr>
<th>Protein</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Whey</strong></td>
<td></td>
</tr>
<tr>
<td>$\beta$-lactoglobulin</td>
<td>55</td>
</tr>
<tr>
<td>$\alpha$-lactalbumin</td>
<td>15</td>
</tr>
<tr>
<td>Immunoglobulins</td>
<td>12</td>
</tr>
<tr>
<td>Casein macropetides</td>
<td>10</td>
</tr>
<tr>
<td>Bovine serum albumin</td>
<td>5</td>
</tr>
<tr>
<td>Lactoferrin</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Lysozyme</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Lactoperoxidase</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Sulphhydryl oxidase</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Superoxide dismutase</td>
<td>&lt;1</td>
</tr>
<tr>
<td><strong>Casein</strong></td>
<td></td>
</tr>
<tr>
<td>$\alpha$-Casein</td>
<td>48</td>
</tr>
<tr>
<td>$\beta$-Casein</td>
<td>35</td>
</tr>
<tr>
<td>$\gamma$-Casein</td>
<td>5</td>
</tr>
<tr>
<td>$\kappa$-Casein</td>
<td>12</td>
</tr>
</tbody>
</table>
17.2.2 Micronutrients

Commercial milk is rich in numerous essential vitamins and minerals (Table 17.1)\(^3\) that help to support the growth and development of the newborn. Macrominerals include calcium, magnesium, sodium, potassium, and phosphorus, and trace elements include iron, copper, zinc, and selenium.\(^8\) In each serving of milk, the predominant minerals include calcium, phosphorus, and potassium, whereas magnesium, zinc, and selenium are present in lesser amounts.\(^5\) Dairy consumption helps to achieve nutritional adequacy for dietary calcium (67% of dietary recommendations), phosphorus (41%), potassium (21%), magnesium (17%), zinc (24%), selenium (19%), and protein (28%).\(^9\) Other trace elements (i.e., copper, iron) are negligible and do not contribute appreciably to meeting dietary requirements (<2%).

Dairy milk is also rich in B-vitamins that support energy metabolism and the synthesis of neurotransmitters and hormones.\(^8\) These include thiamin, riboflavin, niacin, folate, and vitamins B\(_6\) and B\(_{12}\); dairy milk helps to achieve 15%–20% of their dietary requirements for many individuals.\(^10\) Milk also contains fat-soluble vitamins,\(^8\) but these vary depending on its fat content, consistent with their affinity for the triglyceride-rich milk fat fraction.\(^8\) Whole milk is a good source of vitamin A, whereas its content in fat-free milk varies.\(^10\) To circumvent variations, commercial milk is fortified with vitamin A (400–500 IU) and consumption contributes ∼30% to achieving dietary requirements.\(^9\) Although milk consumption contributes ∼60% of daily vitamin D needs, milk is naturally low in vitamin D (∼5 IU).\(^8\) Thus, most commercial milk in the United States and Canada is also fortified with vitamin D (124 IU) to improve intakes and promote bone health and other essential vitamin D functions.\(^11\) Consistent with the nutrient-rich content of dairy milk, it has been suggested that if daily recommendations for dairy were met, it would greatly reduce the number of individuals who routinely fail to meet recommended daily intakes of calcium, magnesium, and vitamins A and D.\(^4\)

17.2.3 Immunoglobulins

Milk is not only the primary energy and nutrient source for newborns, but also delivers components necessary for host immunity. Immunoglobulins (Ig), or antibodies, are proteins produced by white blood cells that maintain host defense.\(^6\) In bovines, transfer of Ig to the newborn occurs postnatally via colostrum, whereas Ig are transferred by the placenta in humans.\(^6\) The main classes of Ig in bovine milk include IgG, IgA, and IgM.\(^6\) These are important because they provide the first line of defense to fight infection against pathogens and toxins, they regulate immune responses, and help to protect mucosal surfaces, including those of the gastrointestinal tract, from invading pathogens.\(^12\)

17.2.4 Processing and Nutritional Composition

Commercial dairy milk differs from raw milk in that it has undergone processing, specifically pasteurization, to minimize potential disease-causing pathogens and spoilage microorganisms to improve shelf-life.\(^13\) Pasteurization involves heating milk to no less than 72°C for at least 15 seconds before being cooled and packaged. This is required by law for all commercial milk in the United States and Canada.\(^13, 14\) In the early 1920s, the U.S. Public Health Service developed the Standard Milk Ordinance, now known as the Grade A Pasteurized Milk Ordinance, to implement pasteurization programs.\(^14\) This was implemented in response to milk accounting for ∼25% of all foodborne illness outbreaks; today it is <1%.\(^13\)

Proponents of raw milk claim that pasteurization destroys the nutrient profile.\(^14\) To the contrary, a meta-analysis examining pasteurization on vitamin levels indicated no significant alterations in riboflavin or vitamin A and only minor (<10%) decreases in vitamin C, thiamin, folate, and vitamins B\(_6\) and B\(_{12}\).\(^13\) Other reports demonstrate no difference in mineral\(^15\) or protein\(^14\) content between raw
and pasteurized milk. This indicates that pasteurization limitedly affects nutrient composition while dramatically improving food safety.

17.3 DIETARY RECOMMENDATIONS

The 2015 Dietary Guidelines for Americans (DGA) recommends 2-, 2.5-, and 3-cup serving-equivalents per day of dairy foods for children (2–3 y), children (4–8 y), and adolescents (9–18 y) and adults, respectively; only children between 1–3 y meet recommendations. Declining milk consumption begins in early childhood and decreases further in adulthood. This has resulted in >80% of the U.S. population failing to meet dietary recommendations. Indeed, Americans only achieve ~50% of the daily recommended intake for dairy. Further, an ~20% decrease in total dairy consumption over the past several decades has paralleled the increased consumption of sweetened beverages.

Milk accounts for 51% of all dairy consumption. It is consumed primarily as a plain or flavored beverage, including that added to cereal or other beverages (Figure 17.1). Beyond milk, the remainder of dairy intakes occur from cheese (45%) and to a much lesser extent fermented products (4%). Concern has been raised that dairy products such as milk are commonly consumed as part of sweetened beverages and cereals, whereas cheese is typically added to meals that are high in

saturated fat (e.g., burgers, pizza, pasta). Thus, dairy consumption is often part of an energy-dense dietary pattern that exceeds recommendations for energy, sugar, and saturated fat. For this reason, the DGA recommends choosing low-fat dairy products to limit saturated fat intakes from full-fat dairy milk and cheese. However, consumption of dairy fat only contributes ∼13% of total fat intake, and may not be as detrimental to health as once thought.

Dairy intakes vary across ethnicities, gender, and socioeconomic status. African Americans tend to consume fewer dairy foods compared with Caucasians and Hispanics, and females less so than males. Intakes are higher among those with greater education and income, and peers and parents also influence consumption. Successful nutrition education programs focusing on teaching children and parents/caregivers to identify and prepare healthy foods and meals are therefore at the forefront of strategies to promote increased dairy milk consumption.

17.4 MILK AND PHYSICAL PERFORMANCE

Nutrition is an instrumental component of training programs to optimize athletic performance. This practice has been observed since the time of the ancient Greeks, who believed that high-protein diets were essential for athletes. This is still observed today in bodybuilders, who typically consume diets that are more than double the recommended amount of protein for non-athletes. Food processing efforts have facilitated this practice, with casein and whey protein supplements being readily available, accounting for billions spent annually.

Unlike whey and casein supplements, milk as a sports nutrition beverage has been studied limitedly, but some evidence supports its use to promote athletic performance. Low-fat milk has several benefits for post-exercise recovery (Figure 17.2). Although provided as lactose, the quantity of milk carbohydrate is similar to that found in popular sports beverages. The high casein content is also digested slowly, which facilitates a more sustained increase in circulating amino acids. Thus, casein is considered a “slow-release” protein, whereas whey is a “fast-release” protein. Whey protein also contains a high proportion of branched chain amino acids that potentiate protein synthesis. Milk is also rich in electrolytes that can help offset exercise-induced losses.

FIGURE 17.2 Observed effects of the consumption of dairy milk and/or its components on health outcomes.
Acute ingestion of milk, and whey and casein proteins, following a single bout of resistance exercise stimulates muscle protein synthesis. Milk ingestion after each bout of resistance exercise during a 10-week training regime also increased muscle protein accretion. Chronic milk ingestion improves body composition by increasing lean body mass and reducing fat mass in young men. These findings suggest that milk is an effective recovery beverage for post-resistance exercise training. Milk ingestion during endurance exercise also helped to decrease protein catabolism post-exercise and resulted in decreased protein synthesis and increased protein oxidation. Ingesting low-fat chocolate milk immediately following and at 2 hours after a high-intensity workout (during a 4-h recovery period) resulted in increased cycling capacity during an endurance trial following the recovery period that same day. Chocolate milk may also have benefits as a recovery beverage.

17.5 MILK CONSUMPTION AND HEALTH PROMOTION

17.5.1 WEIGHT MANAGEMENT

Milk consumption has been studied for its weight management benefits (Figure 17.2). Favorable findings in these areas likely contribute to the overall benefits of dairy foods on cardiometabolic risk. In support, dairy milk consumption has been linked to greater satiety and appetite control to reduce meal-time food intake. In overweight adults, the inclusion of skim milk compared with fruit juice as part of a mixed breakfast improved feelings of satiety and decreased lunch-time food intake by 8.5%. Whey supplementation (60 g/d; 12-weeks) in overweight/obese adults also increased satiety by 15%–20% and fullness by 11%–20% fullness compared with supplementation of casein or glucose. However, a review of controlled clinical trials suggested that no differences exist between whey and casein on appetite control under acute or chronic conditions.

Reduced appetite and increased satiety by milk should mediate favorable effects on body composition. Adolescent girls (15–18 years of age) who consumed milk (1.7 servings/d) had lower body mass index and adiposity. However, other studies suggest a link between higher body mass index and milk intakes. In a longitudinal study of U.S. adolescents (9–14 years of age), those consuming >3 servings/d of milk had greater increases in body mass index (0.09 kg/m²) compared with those consuming <3 servings/d (0.06–0.07 kg/m²). This may be due to milk promoting lean muscle mass accretion, which was not studied. In a randomized controlled trial, 23 weeks of dietary whey protein concentrate supplementation (56 g/d) compared with a carbohydrate control in overweight/obese adults resulted in a greater loss of body mass (1.8 kg) and fat mass (2.3 kg) and reduced waist circumference (2.4 cm). Further, reduced-fat milk consumption (235–435 g/d) among middle-aged obese adults was associated with lower BMI, waist circumference, and body fat percentage.

17.5.2 CARDIOMETABOLIC HEALTH

Cardiometabolic health encompasses the risk for cardiovascular-related mortality and metabolic diseases such as metabolic syndrome (MetS) and type 2 diabetes mellitus (T2DM). Greater milk intakes are associated with lower risks for CVD, MetS, and T2DM (Figure 17.2). A meta-analysis of prospective cohort studies indicates that 200 mL/d of milk is associated with a 6% lower risk for CVD. Greater milk consumption was also associated with a 25% lower risk for developing MetS. In a prospective study of elderly Mediterranean individuals (55–80 y) at risk for CVD, the consumption of >400 g/d of low-fat milk was associated with a 20% lower incidence of MetS. Meta-analyses of cohort studies support greater intakes of milk and >200 g/d low-fat milk to reduce the risk of T2DM by 8% and 17%, respectively. However, other meta-analyses suggest a neutral effect of higher total milk intake or whole milk on T2DM risk. Further study is clearly needed to clarify these somewhat equivocal outcomes.
MetS and T2DM are characterized by impaired glucose tolerance, insulin resistance, and dyslipidemia. The effects of dairy consumption on these responses has been well-investigated, with many studies reporting favorable outcomes. In an acute study, ingestion of dairy milk with a standardized breakfast (48 g carbohydrate) versus the breakfast alone limited postprandial hyperglycemia.\textsuperscript{52} This is important because postprandial hyperglycemia is a better predictor of cardiovascular-related mortality than fasting glucose.\textsuperscript{43} Co-ingesting low-fat milk with a high-glycemic cereal also attenuated meal-induced glycemic excursions in healthy adults.\textsuperscript{44} Separate controlled studies indicate that the acute glycemia-lowering effects of dairy are likely attributed to its casein and whey proteins.\textsuperscript{45} In contrast, chronic studies examining whey or casein protein supplementation failed to show a benefit on fasting glucose.\textsuperscript{46} Similarly, dietary incorporation of low-fat dairy foods (2 servings as milk out of 3.5 total dairy servings) for 12-weeks did not improve fasting glucose in overweight/obese adults compared with persons who consume lower amounts (<0.5 servings/d).\textsuperscript{47}

Although disparities exist between acute and chronic studies, the blood glucose-lowering effects of dairy milk are likely attributed to delaying gastric emptying, and promoting insulin secretion and sensitivity. Whey and casein ingestion increases circulating levels of the hormones cholecystokinin (CCK) and glucagon-like peptide-1 (GLP-1)\textsuperscript{48} and peptide YY (PYY),\textsuperscript{49} with greater levels occurring in response to whey protein. Each of these hormones is known to influence gastric emptying.\textsuperscript{49} Whey and casein also stimulate insulin release in healthy persons and those with metabolic disorders,\textsuperscript{50} with whey protein typically outperforming casein.\textsuperscript{2} Chronic whey protein supplementation, but not casein, lowered fasting insulin levels and insulin resistance in overweight and obese adults.\textsuperscript{46} These findings are in agreement with studies showing that diets having at least one serving/d of dairy milk is associated with lower fasting insulin and insulin resistance in both healthy\textsuperscript{51} and MetS persons.\textsuperscript{47}

Dairy milk and its components also improve dyslipidemia. For example, a high-fat meal with whey protein limited triglyceridemia to a greater extent than casein in diabetic adults.\textsuperscript{52} The consumption of casein, compared with that of oligosaccharides, with a high-fat meal attenuated postprandial lipemia otherwise induced by the high-fat meal alone.\textsuperscript{53} In hyperlipidemic adults, chronic casein supplementation reduced circulating triglyceride and total cholesterol.\textsuperscript{54} Whey protein compared with glucose or casein for 12-weeks also reduced fasting triglyceride and total and LDL cholesterol in overweight/obese adults.\textsuperscript{46} Six-week consumption of skim milk in healthy men decreased total and LDL cholesterol, whereas whole milk increased these parameters.\textsuperscript{55} Skim milk also lowered total cholesterol and triglyceride in adults with elevated levels of cholesterol.\textsuperscript{56} Thus, dairy milk consumption likely alleviates cardiometabolic disease risk by improving lipidemia, although the benefits may be restricted to specific populations.

### 17.5.3 Cardiovascular Disease

Dairy food intakes relative to cardiovascular disease prevention have received significant attention. Several epidemiological studies have associated higher dairy food intakes with a lower incidence of cardiovascular-related morbidity and mortality. Findings also support that greater milk consumption significantly lowers vascular disease and stroke risk,\textsuperscript{57} although some studies have yielded neutral outcomes.\textsuperscript{36} The benefits of dairy on cardiovascular health may be attributed to its blood pressure-lowering effects consistent with a report of the inverse relation between dairy milk intake and hypertension risk.\textsuperscript{58} However, cardiovascular benefits of dairy milk are also mediated independent of its blood pressure-lowering effects.\textsuperscript{59}

The challenge to interpret most dairy-related prospective studies is that dietary exposure to dairy foods is complex, and they fail to entirely consider that high-dairy diets are likely to displace foods that adversely affect health (e.g., refined carbohydrate). In addition, chronic studies often focus on cardiometabolic biomarkers rather than overt cardiovascular disease. For example, 12 weeks consumption of 3.5 servings/d of dairy foods (with ≥1 serving as milk) lowered
circulating lipid peroxidation biomarkers, including oxidized LDL. These were unaffected among participants randomized to <0.5 servings/d of dairy foods. Further, 5 weeks dietary incorporation of low-fat dairy foods (three total servings/d with one as low-fat milk) improved peripheral arterial tone in adults with underlying endothelial dysfunction. Thus, while these benefits are provocative, they do not necessarily extrapolate to an overt reduction in the incidence of cardiovascular disease.

The benefits of dairy foods on cardiovascular health are likely attributed to casein and whey protein. Indeed, a double-blind, randomized, crossover study in adults with elevated blood pressure showing that dietary whey or casein supplementation for 8 weeks improved brachial artery flow-mediated dilation (FMD) and lowered vascular adhesion molecules. Further, supplementation of casein lactotripeptides in postmenopausal women improved brachial artery FMD, suggesting that bioactive milk protein peptides mediate cardioprotection. Similarly, incorporation of a high-dairy diet (3.5 servings/d, ≥1 serving/d from milk) lowered pro-inflammatory proteins implicated in cardiovascular disease development, including interleukin-6, tumor necrosis factor-α, C-reactive protein, and monocyte chemoattractant protein-1.

Metabolic excursions during the postprandial period have also been implicated to increase cardiovascular risk. Controlled studies in persons with MetS have revealed that the acute ingestion of low-fat dairy milk (2 cups) compared with an energy-matched but higher-carbohydrate rice milk comparison beverage limited postprandial glycemic excursions. Further, while rice milk increased oxidative stress and decreased biomarkers of nitric oxide status in association with decreased brachial artery FMD, these adverse effects did not occur in response to low-fat milk.

Similar to chronic studies, findings of acute or postprandial studies support that the benefits of dairy milk are attributed to its proteins and/or bioactive peptides. Support for this concept is evidenced by controlled studies showing that acute ingestion of a whey protein-derived peptide improved functional measures of vascular health in overweight, middle-aged adults. In part, the benefits of dairy proteins on vascular health are potentially attributed to its anti-inflammatory activities. This is consistent with controlled studies showing that low-fat dairy milk decreases pro-inflammatory markers during a 3-h postprandial period that are otherwise increased by a high-carbohydrate breakfast meal (130 g carbohydrate, 7 g fat, 30 g protein). However, it should be noted that the benefits of dairy consumption on inflammation are somewhat equivocal, with some studies showing a neutral effect, whereas others support an antiinflammatory activity. This is potentially attributed to the diverse sources of dairy foods that have yet to be systematically evaluated for their independent bioactivities. Indeed, it has been recognized that different milk varieties (e.g., non-fat vs. full-fat) need to be carefully evaluated for their potential differential influence on cardiovascular risk.

### 17.5.4 Bone Health

Dairy food intakes relative to bone health have been well-studied (Figure 17.2). Of the many nutrients involved in bone health, calcium, phosphorous, magnesium, and vitamin D are highly abundant in milk. Calcium and phosphorous function to enhance bone mineralization while calcium also functions as a cofactor in nutrient and energy metabolism, stabilizes cell membranes, and facilitates signal transduction in osteoblasts and osteoclasts to regulate skeletal health. Vitamin D increases calcium absorption, maintains circulating homeostasis of calcium and phosphorous, and increases bone mineralization.

Because milk is a dietary-rich source of calcium, magnesium, phosphorous, and vitamin D, recommendations to increase dairy intakes are considered an important strategy to promote bone health. Greater milk intakes are associated with lower bone turnover and higher bone density in elderly men. Lower intakes of milk during childhood and adolescence, especially among females, are associated with lower bone mineral content and density and a greater fracture risk in adulthood.
Regular milk consumption (≥1 serving/d) throughout adolescence and older adulthood, particularly midlife, is associated with greater bone mineral content and density in adults over the age of 65. In contrast, milk consumption during adolescence did not lower future hip fracture risk in elderly women, whereas it was increased for men. Higher rates of fractures have also been observed in children who routinely avoided milk compared with those having greater intakes. The importance of milk relative to bone health has become a public health concern because sugar-sweetened beverages have displaced milk from the diet. This suggests that the risk of bone-related disorders is likely to increase in future decades.

### 17.5.5 Immunity and Cancer

Milk contains numerous immune factors that may help to protect against pathogens. This has resulted in growing interest to investigate whether milk consumption improves immune function and cancer risk. There has been limited study in this area and most study outcomes are equivocal, likely due to the different types of cancer being examined. Nonetheless, evidence suggests that milk consumption is associated with lower risks of colorectal and bladder cancers but may actually increase the risks for prostate cancer and lymphatic and renal cancers. In contrast, other studies suggest no relation between milk consumption and the risk of lung, breast, or gastric cancers. Clearly, correlative data cannot be used to establish causality. For this reason, the mechanism by which dairy foods regulate the risk of cancer is under study, but its anti-inflammatory activities may mediate the benefits.

### 17.6 Potential Benefits of Milk Fat

Whether milk fat adversely affects health risk is a controversial area. Because fat-containing varieties of milk contain what is perceived as excess energy, the consumption of non-fat or low-fat dairy products has been recommended over full-fat dairy foods (e.g., whole milk) to promote cardiometabolic health. These recommendations have adversely impacted the consumption of whole milk. To the contrary, dairy fat may actually enhance cardiometabolic health without adversely affecting body composition and obesity. For example, whole milk consumption (≥1 serving/d) was not associated with greater weight gain or a risk of becoming overweight or obese in middle-aged and older women. Whole milk (≥1 serving/d) also correlated with less weight gain in middle-aged women. Latino children who consumed more whole milk were also less likely to become obese.

The benefits of milk fat may be attributed to its favorable effects on glycemic control, circulating lipids, blood pressure, and vascular function. Although it is unclear if whole milk increases insulin sensitivity, controlled studies in overweight/obese adults show that it outperforms skim milk to alleviate postprandial hyperglycemia that is otherwise induced by a standardized meal. Whole milk (0.5 L/d; 3 weeks) compared with skim milk also increased circulating HDL-cholesterol in healthy adults without affecting fasting concentrations of total cholesterol, LDL-cholesterol, triglyceride, glucose or insulin. Further, replacing full-fat milk and cheese with skim milk and half-fat cheese or carbohydrates for 24-weeks did not improve brachial artery FMD or arterial stiffness. Systolic and diastolic blood pressure, at least in normotensive adults, were also unaffected by the chronic consumption of whole milk and yogurt (3.5 servings/d) compared with their low-fat equivalents. Other studies have also shown that three daily servings of regular-fat milk for 6 weeks compared with a milk-free diet had no effect on intracellular and vascular adhesion molecules or endothelin-1. In older men, higher intakes of milk fatty acids were associated with reduced LDL particle atherogenicity, but the effects occurring in a fatty acid-specific manner were not investigated. Indeed, ~400 unique fatty acids make up milk fat, and palmitoleic acid, oleic acids, and CLA may...
confer health benefits.\textsuperscript{93–95} It has therefore been suggested that milk-derived saturated fatty acids are unlikely to adversely affect cardiometabolic outcomes.

**17.7 FERMENTED MILK PRODUCTS IN HUMAN HEALTH**

It should be recognized that dairy milk is a diverse biological matrix containing bioactive proteins and is used in formulation of numerous food products, including cheese, kefir, and yogurt. It must be acknowledged that, while many studies support dairy consumption to improve health, it is difficult to establish independent or additive effects of various milk products. Fermented dairy products (e.g., cheese, yogurt, kefir) are no exception, and are also associated with positive health benefits. For example, cheese may improve cardiometabolic health.\textsuperscript{59, 87} These benefits may be attributed to lactic acid-producing bacteria (i.e., \textit{Lactobacillus} and \textit{Bifidobacterium}) that are used to produce fermented dairy products.\textsuperscript{96}

**17.8 LACTOSE INTOLERANCE**

A leading reason that individuals, particularly adults, fail to achieve dietary recommendations for dairy is lactose intolerance.\textsuperscript{9} Lactose is the major disaccharide in milk and must be hydrolyzed to glucose and galactose for intestinal absorption.\textsuperscript{97} Lactase activity is greatest at birth, presumably to facilitate efficient energy absorption, but declines among infants when they are weaned from the lactating mother. Lactase activity further declines in an age-dependent manner, which is referred to as lactase non-persistence or deficiency (i.e., hypolactasia).\textsuperscript{97–99} Impaired lactose digestion at the small intestine results in unabsorbed lactose in the distal bowel.\textsuperscript{97–99} It is then subjected to fermentation by colonic bacteria, which generates short chain fatty acids along with gaseous byproducts (i.e., hydrogen, carbon dioxide, methane).\textsuperscript{97, 98} The increased colonic presence of lactose not only increases osmotic pressure but also greater localization of water.\textsuperscript{98} These provoke gastrointestinal symptoms, including abdominal pain, bloating, diarrhea, and flatulence.\textsuperscript{97} However, moderate lactase activity (50%) is sufficient to digest lactose and prevent untoward effects.\textsuperscript{98, 100} Lactose malabsorption is commonly diagnosed by feeding 20–50 grams of lactose prior to a lactose tolerance test or breath hydrogen test.\textsuperscript{98, 101} Age-dependent declines in lactase digestion are attributed to the down-regulation of the gene that encodes lactase. Nearly two-thirds of the global population experience age-associated decreases in lactase expression, but rates of lactase persistence vary considerably by geographic region (Table 17.3).\textsuperscript{98, 102} Descendants from societies that raise cattle (e.g., Scandinavia, Netherlands) appear to maintain functional lactase into adulthood.\textsuperscript{98} Lactase persistence is typically greatest (>90%) in northern Europe, and relatively high (~50%) in central and southern Europe and parts of the Middle East and West Africa where cattle farming is prevalent.\textsuperscript{103} However, low rates occur in the rest of Africa (~5%–20%) and Asia (<5%).\textsuperscript{103} Lactose intolerance is broadly characterized by gastrointestinal symptoms occurring in response to lactose ingestion.\textsuperscript{98, 100, 104} Rates of lactose intolerance also vary by geographic region and by ethnicity. The highest rates have been observed among Asians (~90%), Native Americans and African Americans (~70%), and Hispanics (~50%), whereas Caucasian populations have the lowest rates (6%–24%).\textsuperscript{104} Many individuals with lactose intolerance can actually tolerate small amounts of lactose alone (~12 g; equivalent to 1 cup of milk) or in combination with meals (~20 g) without experiencing gastrointestinal discomfort.\textsuperscript{98, 101} The major consequence associated with reduced milk consumption is typically a lack of adequate dietary calcium.\textsuperscript{97} Recommended strategies to achieve adequate calcium status without provoking lactose intolerance-related side effects include eating fermented dairy products (i.e., cheese, yogurt) that are low in lactose, lactose-free milk, and prebiotic or lactase supplements.\textsuperscript{98, 104}
17.9 CONCLUSION

Milk is a complex food and biological matrix that provides several nutrients important for promoting cardiometabolic and bone health and athletic performance. Its bioactive casein and whey proteins and lipids (e.g., CLA) are likely responsible for these health benefits. Despite its nutrient-rich profile, most adolescents and adults fail to meet dietary recommendations for dairy foods, a trend that is further complicated by disparities in consumption by gender, race, and socioeconomic status. The primary barrier for meeting recommended intakes is largely attributed to age-related increases in lactose intolerance in parallel with the greater consumption of alternative beverages in the food supply that are generally less nutrient rich than dairy milk. Although controversial, the emphasis on consuming low-fat dairy products for favorable health outcomes requires careful evaluation. This is consistent with growing knowledge that dairy fat may mediate, at least in part, a portion of the health benefits of dairy milk.

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