Bone nutrients for vegetarians[1–3]

Ann Reed Mangels

ABSTRACT

The process of bone mineralization and resorption is complex and is affected by numerous factors, including dietary constituents. Although some dietary factors involved in bone health, such as calcium and vitamin D, are typically associated with dairy products, plant-based sources of these nutrients also supply other key nutrients involved in bone maintenance. Some research suggests that vegetarian diets, especially vegan diets, are associated with lower bone mineral density (BMD), but this does not appear to be clinically significant. Vegan diets are not associated with an increased fracture risk if calcium intake is adequate. Dietary factors in plant-based diets that support the development and maintenance of bone mass include calcium, vitamin D, protein, potassium, and soy isoflavones. Other factors present in plant-based diets such as oxalic acid and phytic acid can potentially interfere with absorption and retention of calcium and thereby have a negative effect on BMD. Impaired vitamin B-12 status also negatively affects BMD. The role of protein in calcium balance is multifaceted. Overall, calcium and protein intakes in accord with Dietary Reference Intakes are recommended for vegetarians, including vegans. Fortified foods are often helpful in meeting recommendations for calcium and vitamin D. Plant-based diets can provide adequate amounts of key nutrients for bone health. *Am J Clin Nutr* 2014;100(suppl):469S–75S.

INTRODUCTION

Osteoporosis affects millions of people and has significant effects on quality of life and on health care costs. Worldwide, ~1 of 3 women and 1 of 5 men aged >50 y will experience a fracture related to osteoporosis (1). In 2000, there were an estimated 9 million osteoporotic fractures worldwide, resulting in 5.8 million disability-adjusted life-years lost (2). The annual cost of osteoporosis and fractures in elderly people in the United States was projected to be $22 billion in 2008 (3); more recent estimates are not available.

Nutrition plays a part in reducing the risk of developing osteoporosis. Nutrients that appear to have important roles in bone health include calcium, vitamin D, protein, phosphorus, magnesium, zinc, copper, manganese, vitamin C, vitamin B-12, vitamin K, and potassium. Some of these nutrients are essential for the growth and development of the skeleton, some are involved in the formation of collagen or cartilage, and some support calcium and phosphate homeostasis (4). In addition, phytoestrogens, flavones, and antioxidants as well as fruit, vegetables, soy products, and many other factors related to diet may have implications for bone health.

Vegetarians are a diverse group of individuals characterized by an avoidance of meat (including fowl) and seafood and products containing these foods (5). Generally, vegetarian diets are categorized on the basis of foods included or excluded, with lactoovovegetarian diets including dairy products and eggs, lactovegetarian diets including dairy products, and vegan diets excluding all animal products. Even within these categories, considerable heterogeneity exists (6). Common food and supplement sources of nutrients related to bone health in different types of vegetarian diets are shown in **Table 1**. Of course, individual variation occurs in food and supplement choices and can affect the sources and adequacy of these nutrients.

Two recent large studies compared nutrient intakes in vegetarians and nonvegetarians (7, 8). The first study, the European Investigation into Cancer and Nutrition (EPIC)[4]–Oxford, examined dietary intakes of 29,913 meat eaters, 16,095 lactoovovegetarians and lactovegetarians, and 2112 vegans in the United Kingdom (7). The mean percentage of energy from protein was 16.0% in male meat eaters, 13.1% in male vegetarians, 12.9% in male vegans, 17.3% in female meat eaters, 13.8% in female vegetarians, and 13.5% in female vegans (7). Vegans had the highest intakes of vitamin C and magnesium and the lowest intakes of vitamin B-12, vitamin D, calcium, and zinc (statistical significance not indicated) (7). The second study compared nutrient intakes of different groups of adult Seventh-day Adventists from the United States and Canada and included 33,634 meat eaters, 21,799 lactoovovegetarians, and 5694 vegans (8). Mean intakes of protein (% of energy), vitamin B-12, vitamin C, calcium, sodium, phosphorus, and zinc did not differ between groups (8). Lactoovovegetarians and vegans had significantly higher intakes of total fiber; vegans had significantly lower intakes of vitamin D and significantly higher intakes of magnesium compared with nonvegetarians ($P < 0.05$ for all) (8).

Whereas dietary factors and the propensity of many vegetarians to lead an active lifestyle can promote bone health, there is also evidence that vegetarianism is associated with several factors that can have a detrimental impact on bone health, namely a lower average BMI (9) and potentially low intakes of vitamin B-12 (10), calcium (7, 11), and vitamin D (7, 8, 12–14). The purpose of this

[1] From The Vegetarian Resource Group, Baltimore, MD.

[2] Presented at the symposium "Sixth International Congress on Vegetarian Nutrition" held in Loma Linda, CA, 24–26 February 2013.

[3] Address correspondence to AR Mangels, The Vegetarian Resource Group, PO Box 1463, Baltimore, MD 21203. E-mail: reed@vrg.org.

[4] Abbreviations used: BMD, bone mineral density; EAR, Estimated Average Requirement; EPIC, European Prospective Investigation into Cancer and Nutrition; RDA, Recommended Dietary Allowance; 25(OH)D, 25-hydroxyvitamin D.

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TABLE 1
Dietary and supplement sources of some nutrients involved in bone health in different types of vegetarian diets

Nutrient	Lactoovovegetarian sources	Lactovegetarian sources	Vegan sources
Calcium	Dairy products, calcium-fortified foods, green leafy vegetables, calcium supplements	Dairy products, calcium-fortified foods, green leafy vegetables, calcium supplements	Calcium-fortified foods, green leafy vegetables, calcium supplements
Potassium	Dairy products, legumes, vegetables, fruit	Dairy products, legumes, vegetables, fruit	Legumes, vegetables, fruit
Protein	Dairy products, eggs, legumes, grains, nuts, seeds	Dairy products, legumes, grains, nuts, seeds	Legumes, grains, nuts, seeds
Vitamin B-12	Dairy products, eggs, vitamin B-12–fortified foods, vitamin B-12 supplements	Dairy products, vitamin B-12–fortified foods, vitamin B-12 supplements	Vitamin B-12–fortified foods, vitamin B-12 supplements
Vitamin C	Fruit, vegetables	Fruit, vegetables	Fruit, vegetables
Vitamin D	Vitamin D–fortified dairy products, eggs, vitamin D–fortified foods, vitamin D supplements, mushrooms	Vitamin D–fortified dairy products, vitamin D–fortified foods, vitamin D supplements, mushrooms	Vitamin D–fortified foods, vitamin D supplements, mushrooms

article is to review the adequacy of a plant-based diet for healthy bones, to examine constituents of a plant-based diet that may offer benefits in terms of bone health, and to provide practical recommendations for promotion of bone health in vegetarians and those consuming primarily plant-based diets.

BONE MINERAL DENSITY AND FRACTURE RISK IN VEGETARIANS

Two indicators of bone health are bone mineral density (BMD) and bone fragility, as evidenced by fracture incidence. A number of studies examined these indicators in vegetarians.

BMD is a consistent predictor of the risk of osteoporotic fracture (15). Studies of BMD in vegetarians yielded inconsistent results, with some reporting no significant difference and some reporting lower BMDs in vegetarians compared with nonvegetarians (16). Inconsistencies between studies may be attributable to small sample sizes, differences in types of vegetarians studied, and failure to control for factors such as BMI, physical activity level, and nutrient intake.

To resolve the inconsistent results, Ho-Pham et al (16) carried out a Bayesian meta-analysis to estimate the magnitude of the effect of vegetarian diets on BMD. Nine studies of BMD in vegetarians were included in the analysis; more than half of the studies were in women. Femoral neck and lumbar spine BMD was 4% lower in those categorized as vegetarians (including both lactoovovegetarians and vegans) compared with omnivores. BMD was 6% lower at the femoral neck in vegans than in nonvegetarians, with similar results for BMD at the lumbar spine. These differences were assessed as being very modest and not clinically relevant in terms of risk of fracture (16).

The EPIC-Oxford study examined fracture risk in meat eaters, fish eaters, vegetarians (who also consumed dairy products and/or eggs), and vegans (17). The >34,000 study subjects ranged in age from 20 to 89 y. Subjects were followed for an average of 5.2 y, and fractures were self-reported. Fracture risk was highest among vegans, although this association was attenuated when adjustments were made for nondietary factors such as smoking and alcohol. When only those subjects with calcium intakes above the UK Estimated Average Requirement (EAR) for calcium of 525 mg/d were included in the analysis, there was no difference between any of the groups in terms of fracture incidence (17). These results suggest that calcium adequacy plays a role in bone health. The results of this study are supported by other epidemiologic studies showing that, in populations with low mean calcium intakes, risk of fracture was increased (18, 19), whereas in populations with average mean calcium intakes, this association was not seen (20).

Other studies of fracture risk in vegetarians found no significant difference in vertebral fracture risk in Vietnamese postmenopausal women (vegan compared with nonvegetarian) (21) but a higher risk of wrist fracture in vegetarian Adventist women (22). Results of the latter study may have been influenced by dietary protein intake (22).

Overall, vegetarians appear to have BMD similar to nonvegetarians. Fracture rates are similar in vegetarians and nonvegetarians if calcium intake is adequate and the diet contains good sources of protein. Clearly, vegetarian diets, including vegan diets, can support bone health.

CALCIUM AND BONE HEALTH FOR VEGETARIANS

Calcium is the nutrient most commonly associated with bone health. Most of the calcium in the human body is found in the bones and teeth where it serves as a major structural element. Bone tissue also functions as a source of calcium for metabolic needs.

The US Dietary Reference Intakes for calcium and vitamin D were most recently updated in November 2010 using current scientific knowledge. One significant change was the move from the use of Adequate Intakes to EARs and Recommended Dietary Allowances (RDAs) for calcium and vitamin D (**Table 2**). The Adequate Intake is based on estimates of nutrient intake by a group of people who are apparently healthy and who are therefore assumed to have an adequate intake and is used when an RDA cannot be determined because of limited data (23). Some publications for the general public have suggested that vegetarians, especially vegans, may not need as much calcium as nonvegetarians because of vegetarians' lower protein and lower animal-derived protein intakes. As a later section of this article suggests, higher protein intakes appear to be beneficial to bone health. In addition, there is no evidence that vegetarians, including vegans, have lower calcium needs because of the protein content of their diet. On the basis of current knowledge, it seems prudent to recommend

TABLE 2
Dietary Reference Intakes for calcium and vitamin D by age and sex in the United States and Canada[1]

	Dietary Reference Intake (reference)			
Age group	Calcium EAR (23)	Calcium RDA (23)	Vitamin D EAR (23)	Vitamin D RDA (23)
	mg/d	*mg/d*	*IU/d*	*IU/d*
1–3 y	500	700	400	600
4–8 y	800	1000	400	600
9–18 y	1100	1300	400	600
19–50 y	800	1000	400	600
51–70 y				
Women	1000	1200	400	600
Men	800	1000	400	600
>70 y	1000	1200	400	800

[1] EAR, Estimated Average Requirement; RDA, Recommended Dietary Allowance.

that vegetarians strive to meet the calcium Dietary Reference Intakes.

A variety of studies in Western vegetarians published over the past 20 y showed that mean calcium intakes of groups of vegetarians and vegans do not necessarily meet the US EAR, an average daily nutrient intake amount estimated to meet the needs of half of healthy individuals (23). For example, male lactoovovegetarians have mean calcium intakes ranging from ∼700 mg to close to 1600 mg/d, whereas intakes of male vegans range from 400 to 900 mg/d (11). Female lactoovovegetarians' mean calcium intakes range from ∼650–1150 mg/d, whereas female vegans' mean intakes range from 425 to 800 mg/d (11).

Although dairy products are widely advertised as sources of calcium, a number of plant-based foods also contain well-absorbed calcium. These include green leafy vegetables such as bok choy, kale, and broccoli; tofu set with calcium salts; and calcium-fortified foods including plant milks, orange juice, and energy bars. Approximately 30% of calcium is absorbed from dairy products and fortified foods; almost twice as much is absorbed from some vegetables such as broccoli and kale (23).

One method for promoting calcium intake for individuals choosing plant-based or vegan diets is to devise a list of foods that contain similar amounts of well-absorbed calcium (24, 25). Selecting a specified number of servings of these foods can allow clients flexibility in meeting calcium recommendations. Foods that contain ∼150 mg of calcium per serving are listed in **Figure 1**. Assuming that other foods will provide additional, smaller amounts of calcium, the use of at least 5–6 servings of these foods/d for younger adults and at least 7 servings/d for postmenopausal women and men aged ≥71 y can provide a simple way to meet recommendations for calcium.

Calcium bioavailability from plant foods is especially affected by the presence of oxalic acid and phytic acid in some foods. Foods high in oxalic acid include spinach, rhubarb, Swiss chard, and beet greens. Fractional absorption of calcium from these foods may be as low as 5%; in comparison, low-oxalate vegetables such as broccoli and bok choy have a fractional absorption of >50% (26). Foods high in phytic acid include wheat bran, legumes, seeds, nuts, and soy isolates (23). Plant-based foods that contain approximately the same amount of absorbable calcium as 1 cup of cow milk are shown in **Table 3**.

It is entirely possible for vegetarians, including vegans, to meet the current recommendations for calcium. Judicious food selection, including possible use of some calcium-fortified foods, can help to ensure calcium adequacy.

PROTEIN, CALCIUM, AND THE SKELETON

It has long been known that an increase in dietary protein results in an increased urinary calcium excretion (29). At one point, this effect of protein was used to support the idea that vegetarians, whose diets could conceivably be lower in protein, would have lower urinary calcium losses, and thus would require less calcium. More recent research suggests that the influence of dietary protein on calcium needs is much more complex (30, 31) and that higher protein diets may provide benefits in terms of bone health (32–34).

Protein has a number of potentially positive effects on bone health (31). The increased insulin-like growth factor I seen with higher protein intakes may increase osteoblast activity and promote mineralization of the bone matrix (34). Higher protein intakes may improve calcium absorption, especially from diets low in calcium (35, 36). Protein also helps to maintain bone structure (37), suppresses parathyroid hormone (38), and improves muscle strength (37), all of which may provide benefits in terms of bone health.

The increased calciuria seen with increased dietary protein could have a negative effect on the skeleton if the source of the urinary calcium was bone resorption. In addition, the increased dietary acid load associated with a higher protein intake, especially with a higher intake of sulfur-containing amino acids, may lead to a shift in the balance between osteoblastic and osteoclastic activity (34). Newer research, however, suggests that the serum

- **2 Tablespoons** almond butter, tahini
- **1/4 cup** calcium-fortified tofu, almonds
- **1/2 cup** calcium-fortified plant milk, calcium-fortified orange juice, tempeh, soybeans, firm tofu made with calcium and nigari, calcium-fortified yogurt
- **1 cup** cooked bok choy, collards, kale, mustard greens, okra, white beans
- **2 cups** cooked broccoli
- **1/2** calcium-fortified energy bar
- **2** navel oranges
- **10** dried figs

FIGURE 1. Foods that contain ∼150 mg of calcium per serving.

TABLE 3
Plant-based foods that contain approximately the same amount of absorbable calcium [96 mg (26)] as 1 cup (240 mL) of cow milk

Food (reference)	Amount
Vegetables (26)	
Bok choy	1 cup (170 g)
Broccoli	2.25 cups (160 g)
Chinese cabbage	0.5 cups (85 g)
Kale	1.5 cups (255 g)
Beans and soy products	
Calcium-fortified soy milk (27)	1.3 cups (312 mL)
Calcium-set tofu (26)	5.4 ounces (153 g)
White beans (26)	2 cups (220 g)
Other	
Calcium-fortified juice (26,28)	0.6–1 cup (144–240 mL)

pH change that occurs in response to an acid-generating diet is not of the magnitude needed to activate the osteoclastic cells to promote bone resorption (31).

Despite protein's possible negative role in bone health, a recent systematic review and meta-analysis concluded that only 1–2% of BMD could be attributed to protein intake and that protein intake had either a positive or neutral effect on BMD (34). Protein intake either reduced or did not affect the risk of hip fracture regardless of the form of protein (animal compared with vegetable) (34).

Limited research has directly examined the role of protein in the bone health of vegetarians. A cohort study in 1865 peri- and postmenopausal women who were followed for 25 y examined the effects of meat consumption or a vegetarian diet on the risk of wrist fracture (22). Vegetarian women with the lowest consumption of vegetable protein (beans, nuts, soy milk, and meat analogs) had the highest risk of forearm fracture. There was a 68% reduction in risk of wrist fracture risk (HR: 0.32; 95% CI: 0.13, 0.79) in the vegetarian women who had vegetable protein more than once a day compared with the vegetarian women who had vegetable protein <3 times/wk (22). Similar results, with lower fracture risk for higher intakes, were also seen for beans, meat analogs, and cheese (22). A larger study that included >17,000 male and female vegetarians found that those with the highest intakes of meat analogs had a reduction in risk of hip fracture compared with those with the lowest intakes (HR: 0.34; 95% CI: 0.12, 0.95) (39). Those with the highest intakes of legumes had a reduction in risk of hip fracture compared with those with the lowest intake (HR: 0.48; 95% CI: 0.24, 0.97) (39). These results support the idea that protein-rich foods are associated with bone health in vegetarians.

Protein intakes of vegetarians vary depending on food choices. Surveys suggest that protein intakes of nonvegetarians are frequently in the range of 14–18% of energy, whereas lactoovovegetarian and vegan protein intakes are between 12–14% and 10–12% of energy, respectively (11). Sources of protein also vary by diet type. For example, mean animal protein (% of energy) ranged from 6.2% in nonvegetarians to 2.4% in lactoovovegetarians to 0.6% in vegans in one study in Seventh-day Adventists (8). In the same study, mean plant protein ranged from 8.5% in nonvegetarians to 11.4% in lactoovovegetarians to 13.0% in vegans (8).

Although it is clear that increasing dietary protein is associated with increased calcium loss in the urine, the source of this calcium is subject to debate. One hypothesis is that higher amounts of calcium appear in the urine, mainly attributable to the greater calcium absorption that occurs with a high-protein diet. Short-term dietary intervention studies support this idea (35). Increased protein intake reduces calcium reabsorption by the kidney, possibly because of an increased glomerular filtration rate (30). This could help to explain the higher urinary calcium losses seen with higher protein intakes. An additional hypothesis is that a diet high in acid-producing foods, commonly foods high in sulfur-containing amino acids such as meats and grains, could lead to a mild metabolic acidemia, which is then buffered by carbonates and other bases from bone. According to this hypothesis, calcium is leached from bone along with these buffering agents, is excreted in urine, and a loss of bone occurs (30). A recent meta-analysis calls into question the idea that the amount or type of protein affects calcium balance or bone resorption (40).

If the higher dietary acid load associated with a higher protein intake does increase calcium losses in urine, it would be beneficial to identify ways to reduce these losses while still seeing the benefits of a higher protein intake. Vegetarians are not exempt from the negative effects of a higher protein intake because vegetarian protein sources such as soy, corn, wheat, and rice have total sulfur contents per gram of protein similar to meat, eggs, and milk (41) and thus have a similar potential to promote calciuria. However, vegetarian diets also can contain many foods with acid-neutralizing potential, such as fruit and vegetables. A combination of adequate protein, fruit, and vegetables and ample dietary calcium may enhance protein's role in the promotion of bone health (30).

VITAMIN D'S ROLE IN BONE HEALTH OF VEGETARIANS

Vitamin D plays a key role in bone health through its promotion of calcium absorption and normal mineralization of bones. This vitamin is naturally present in very few foods, is added to some foods, and can be synthesized endogenously after cutaneous exposure to UV-B radiation from sunlight. Many factors, such as season, skin pigmentation, use of sunscreen, and clothing coverage, affect vitamin D production (23). Dietary and supplemental sources of vitamin D are commonly required to meet the needs for this essential nutrient.

Dairy products are often fortified with vitamin D and can be an important source for lactoovovegetarians and lactovegetarians. Plant milks may also be fortified with vitamin D and can serve as a source for vegans and others who avoid dairy products. These fortified foods are a relatively recent innovation and are not universally available.

In Finland, dietary intake of vitamin D in vegans was insufficient to maintain serum 25-hydroxyvitamin D [25(OH)D] and parathyroid hormone concentrations within normal ranges in the winter; these low concentrations appear to have a negative effect on long-term BMD (12). Lactovegetarians also had significantly lower vitamin D intakes than did nonvegetarians in this study (12). Similar results, namely lower vitamin D intakes in vegans and in lactoovovegetarians or lactovegetarians, were also reported in participants in EPIC-Oxford (13). The Adventist Health Study 2 reported lower dietary vitamin D intakes in non-Hispanic white vegetarians but not in black vegetarians (14). Total vitamin D intakes (diet + supplement) were not significantly different between vegetarians and nonvegetarians (14).

Several studies have examined vitamin D status of vegetarians. EPIC-Oxford reported significantly lower plasma 25(OH)D in vegetarians compared with meat eaters, with vegans having the lowest mean plasma 25(OH)D concentrations (13). Plasma 25(OH)D concentrations <25 nmol/L, a concentration considered by the UK Department of Health to increase the risk of bone-related diseases, were reported in 8% of vegans and 3% of vegetarians when blood was collected in the winter or spring; these low concentrations were less common when blood was collected in summer or fall (13). Lower plasma 25(OH)D was also reported in vegans in Finland (12) and in Vietnam (21).

The identification of good sources of vitamin D is clearly a priority to improve bone health of vegetarians and vegans. Although fortified foods and UV-treated mushrooms are plant-based sources of vitamin D, the amount of vitamin D that they supply is limited (**Table 4**), especially in relation to the current RDA of 600 IU/d for 19–70 y olds and 800 IU/d for those aged >70 y (Table 2) (23). Supplemental vitamin D may be needed. These recommendations were developed on the basis of no sunlight exposure (23); lower dietary intakes of vitamin D may be needed to maintain vitamin D sufficiency in situations in which more sunlight exposure occurs. However, due to the risk of skin cancer, limited exposure of skin to sunlight is recommended (43).

Vitamin D_3 (cholecalciferol) is derived from lanolin from sheep's wool and is typically avoided by vegans. Vitamin D_2 (ergocalciferol) is a vegan source of vitamin D. There is some controversy about the equivalence of these 2 forms of vitamin D (44–47). At low doses, vitamin D_2 and vitamin D_3 appear to be equivalent, but at higher doses vitamin D_2 appears to be less effective than vitamin D_3 (23).

UV-treated mushrooms contain vitamin D_2. A recent study suggests that vitamin D_2 from mushrooms is beneficial for those at risk of vitamin D deficiency but may not improve status in those with considerable sun exposure (48). A vegan form of vitamin D_3 has been isolated from lichen (49).

FRUIT AND VEGETABLES

Diets high in fruit and vegetables offer many potential benefits for bone health. Fruit and vegetables are good sources of nutrients that are involved in bone metabolism, including magnesium, calcium, potassium, vitamin K, and vitamin C (50). The antioxidants found in fruit and vegetables could protect bone by reducing resorption attributable to high oxidative stress (50). Because of the potassium and magnesium content of diets high in fruit and vegetables, dietary acid load is lower, potentially resulting in less loss of calcium in urine (51).

Higher consumption of fruit and vegetables has been associated with decreased risk of fragility fractures (52). In a case-control study in postmenopausal women in China whose diets were low in meat and milk, the estimated OR (95% CI) for forearm fracture was 0.53 (0.42, 0.67) for each quintile increase in vegetable intake (52). Higher intakes of fruit and vegetables also appeared to be protective. These results may be especially relevant for vegans because of their dietary similarities with the women in this study.

Fruit and vegetable consumption has been associated with positive effects on bone (53–55), although not all studies found this association (56, 57). A recent systematic review concluded that it was not clear whether fruit and vegetable intake in postmenopausal women can reduce the risk of osteoporotic fractures, improve BMD, or slow the rate of bone loss (50). These contradictory results may be due to differences in the types of vegetables or fruit that predominate in different populations or to other variables.

The potassium content of fruit and vegetables was proposed as one explanation for the positive effects on bone sometimes associated with fruit and vegetables. Vegetarian, especially vegans, typically have generous intakes of potassium (11). Higher potassium intakes have been associated with greater lumbar spine and femoral neck BMD (58) and with other bone-related benefits (59).

The potassium in fruit and vegetables is predominantly associated with bicarbonate precursors (eg, citrate) (60). Meat, dairy products, and cereals contain potassium but have fewer bicarbonate precursors (60, 61). The association of fruit and vegetables with bone health may be due in part to the presence of bicarbonate precursors (62), which have an alkalizing effect and thereby promote bone health.

Vitamin C, another nutrient whose intake is high in those choosing plant-based diets, has been associated with bone health. For example, in the Framingham Osteoporosis Study, subjects in the highest tertile of intake for vitamin C had significantly fewer hip fractures and nonvertebral fractures compared with those in the lowest tertile (63). These results included vitamin C from diet and supplements. Similar trends were seen when dietary intake alone was assessed, but results were not significant (63). The beneficial effects of vitamin C may be related to its role as an antioxidant (63) and to its function as a cofactor for collagen formation (64). In addition, vitamin C intake may reflect fruit and

TABLE 4
Plant-based sources of vitamin D_2

Food (reference)	Serving size	Vitamin D
		IU
Mushrooms		
Brown or crimini mushrooms (42)	1 cup sliced (72 g)	2
Chanterelle mushrooms (42)	1 cup (54 g)	114
Morel mushrooms (42)	1 cup (66 g)	136
Mushroom powder[1]	1 teaspoon (1.4 g)	600
Mushrooms, commercially exposed to UV light (42)	1 cup diced (86 g)	384
White or portabella mushrooms (42)	1 cup pieces or slices (70–86 g)	3–9
Fortified foods		
Fortified plant milk[1]	8 ounces (240 mL)	40–120

[1] Values based on manufacturers' information.

vegetable intake, and beneficial effects purported to be the results of vitamin C could be attributed to other factors in fruit and vegetables. Despite variability in results, the many positive benefits of fruit and vegetables for both overall and bone health make it apparent that generous amounts of these foods should be recommended.

OTHER FACTORS THAT MAY AFFECT VEGETARIAN BONE HEALTH

Vegetarians commonly use soy products as convenient additions to their diet. The impact of soy foods on bone health is uncertain (65). Epidemiologic studies suggest that women who have high soy food consumption have a lower risk of osteoporosis (66) and report a reduced risk of fracture in women with the highest soy intakes (67, 68). Randomized controlled trials of isoflavone supplements showed mixed results, typically finding positive effects of isoflavones on bone only in very high doses—considerably above usual intakes from soy foods (69, 70).

Inadequate vitamin B-12 status has been linked to low BMD, increased fracture risk, and osteoporosis (71, 72). Vegans who do not regularly use reliable sources of vitamin B-12 are at risk of deficiency. The elevated plasma homocysteine concentrations that are a hallmark of vitamin B-12 deficiency may explain the association between a vitamin B-12 deficiency and poor bone health. Homocysteine was shown to stimulate osteoclasts, inhibit osteoblasts, and disturb collagen crosslinking (73). Even mild to moderate vitamin B-12 deficiency appears to be sufficient to increase bone turnover (73).

CONCLUSIONS

Plant-based diets can provide adequate amounts of key nutrients for bone health. Both vegetarian and vegan diets can have effects on BMD and rates of osteoporotic fracture similar to omnivorous diets. Despite some inconsistencies in research, it is possible to make dietary recommendations that will support bone health in vegetarians. Specifically, vegetarian diets should include the following:

- adequate calcium and vitamin D: these nutrients can come from foods (naturally good sources and fortified products) and, if necessary, from supplements;
- adequate protein from a variety of sources;
- generous amounts of a variety of fruit and vegetables; and
- regular, reliable sources of vitamin B-12 to ensure sufficiency.

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