Consumers are increasingly showing interest in reduced-calorie vegetarian meals. In addition, there has been a proliferation of Web sites and cookbooks dealing with vegetarian issues. Veggie burgers and other vegetarian options are available in fast-food restaurants and university foodservice facilities. The popularity of vegetarian diets in recent years is fueled by ethical considerations, health concerns, environmental issues, and religious factors. The reason a person chooses to be a vegetarian will influence the pattern of foods chosen. A true vegetarian eliminates all flesh foods from the diet, including fish and chicken, and typically bases the diet on fruits and vegetables, grains (preferably whole grains), legumes, and nuts. Some vegetarian diets emphasize raw foods. Lacto-ovo-vegetarians permit dairy and/or egg products. A vegan (or total vegetarian) consumes only plant foods. Even within these broad categories, one observes a wide diversity of dietary practices. This diversity of eating patterns makes it difficult to find clear relationships among the diet, nutrition status, and health profile. The nutrition adequacy of a particular plant-based diet will depend upon the appropriateness of food choices, which are often determined by the nutrition knowledge of the individual and the availability of certain foods, especially fortified foods. A vegetarian diet that uses primarily olive oil as the source of fat, and minimal amounts of dairy and eggs, can be considered nutritionally similar to a Mediterranean-style diet, which is widely considered to be health promoting.

The U.S. market for processed vegetarian foods (such as meat analogs, vegetarian burgers, nondairy milks, and vegetarian entrees) has grown significantly during the past decade. The ready availability of fortified vegetarian foods (such as soymilks and meat analogs) is expected to have a significant impact on the nutrient intake of vegetarians. These foods, along with fortified juices and breakfast cereals, can add substantially to a vegetarian’s intake of calcium, iron, zinc, vitamin B12, vitamin D, osteoporosis; calcium; ω-3; diabetes; research and diseases.

This review discusses the nutrients of major concern in a vegetarian diet along with the health benefits obtained from following a vegetarian diet. A comparison is also made between the 2 forms of vegetarian diets most commonly practiced in North America—a lacto-ovo-vegetarian diet and a vegan diet. The health effects of vegetarian diets have been discussed elsewhere.1,2

### Nutrition Concerns

#### Vitamin D

In addition to being important for the maintenance of bone health, vitamin D plays an important role in immune...
function, the reduction of inflammation, and reducing the risk of chronic diseases. Vitamin D insufficiency has been linked to a wide variety of diseases including type I diabetes, multiple sclerosis, rheumatoid arthritis, colorectal cancer, heart disease, and infectious diseases. Many genes encoding proteins regulating cell proliferation, differentiation, and apoptosis are modulated in part by vitamin D. Adequate vitamin D intake is essential since all tissues in the body have a vitamin D receptor and respond to the active form 1,25-dihydroxyvitamin D. Cutaneous production of vitamin D3 is not adequate (especially in heavy sunscreen users and the elderly) to meet nutrition needs in most parts of North America (north of latitude 35°N) during the winter months, a food source or vitamin D supplement is necessary. A circulating level of 25-hydroxyvitamin D of >37.5 nmol/L is considered an indication of adequate vitamin D status, but a higher level (>75 nmol/L) has been suggested by some to maximize the beneficial effect of vitamin D upon our health. In the absence of adequate sun exposure, about 1000 international units of vitamin D per day may be needed to achieve this level, a value substantially higher than the current dietary reference intake (DRI). Low vitamin D intakes, low serum 25-hydroxyvitamin D levels, and reduced bone mass have been reported in some vegan groups who did not take vitamin D supplements or ingest fortified foods such as cow’s milk; yogurt; some brands of soymilk, rice milk, and orange juice; breakfast cereals; and margarines. Substantial levels of vitamin D2 (400 international units per 3 oz of mushroom) may be obtained from mushrooms that have been exposed to ultraviolet light under controlled conditions. Intake of vitamin D by vegans tends to be substantially below that of lacto-ovo-vegetarians and nonvegetarians (see Table 1). Both vitamin D2 (ergocalciferol, produced from yeast) and, more commonly, vitamin D3 (cholecalciferol, derived from lanolin) are used in supplements and to fortify foods. Vitamin D2 (which contains a double bond at C22 in its side chain, a feature that is lacking in the side chain of D3) appears to be as effective as vitamin D3 in maintaining serum 25-hydroxyvitamin D levels.

Vitamin B12
Because of inadequate consumption, the vitamin B12 status of some vegetarians is less than adequate. Although dairy and eggs are good sources of vitamin B12 for the lacto-ovo-vegetarian, vegans must obtain their vitamin B12 either from a regular use of vitamin B12-fortified foods, such as fortified soy and rice beverages, some breakfast cereals, meat analogs, and Red Star Vegetarian Support Formula nutrition yeast, or from a daily vitamin B12 supplement. Unfortified plant foods (such as seaweeds) do not contain any significant amount of active vitamin B12. If folic acid intake is high, hematological symptoms of vitamin B12 deficiency may be masked and go undetected.

### Table 1. Mean Intakes of Selected Vitamins and Minerals and Linolenic Acid (ω-3) Among Vegetarians and Nonvegetarians

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Dietary Group</th>
<th>Male</th>
<th>Female</th>
<th>n</th>
<th>Years of Publications</th>
<th>DRI for Male</th>
<th>DRI for Female</th>
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<tbody>
<tr>
<td>Calcium, mg</td>
<td>NV</td>
<td>946</td>
<td>898</td>
<td>10</td>
<td>1997-2003</td>
<td>1000</td>
<td>1000</td>
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<td></td>
<td>LOV</td>
<td>906</td>
<td>875</td>
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<tr>
<td></td>
<td>VG</td>
<td>755</td>
<td>622</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Iron, mg</td>
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<td>10</td>
<td>1997-2003</td>
<td>8</td>
<td>18</td>
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<td></td>
<td>LOV</td>
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<td></td>
<td>VG</td>
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<tr>
<td>Zinc, mg</td>
<td>NV</td>
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<td>10.1</td>
<td>9</td>
<td>1997-2003</td>
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<tr>
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<td>1989-2003</td>
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<td>LOV</td>
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<td>VG</td>
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<tr>
<td>Vitamin B12, mcg</td>
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<td>5.4</td>
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<td>1991-2003</td>
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<tr>
<td></td>
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<td>2.1</td>
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<tr>
<td></td>
<td>VG</td>
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<td>1.0</td>
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<tr>
<td>18:3 ω-3, mg</td>
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<td>1.2</td>
<td>4</td>
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</tr>
<tr>
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<td>1.6</td>
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<tr>
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<td>VG</td>
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</table>

DRI, Dietary Reference Intake; LOV, lacto-ovo-vegetarian; NV, nonvegetarian; VG, vegan.
aData from reference 6.
bDRIs are for 19-50 years of age. For iron, calcium and vitamin D values will be different for adults over 50 years of age.
ω-3 (n-3) Fatty Acids

The long-chain ω-3 fatty acids are important for cardiovascular health, infant visual function, and neurodevelopment. Compared with nonvegetarians, vegetarians (and particularly vegans) tend to have lower blood levels of the long-chain ω-3 fatty acids, eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA). Chickens fed ω-3 in their diet produce eggs containing some EPA and DHA. For the vegan, certain microalgae are a good source of DHA, and the oil from brown algae (kelp) is a source of EPA. Rich sources of α-linolenic acid (ALA), the precursor of EPA and DHA, include flaxseed, walnuts, canola oil, chia seed, and soy. However, the bioconversion of ALA to EPA is generally less than 10% in humans, whereas the conversion of ALA to DHA is substantially less. The conversion varies with individuals, and women are known to have a higher ALA conversion efficiency than men. Those with increased requirements of ω-3, such as pregnant and lactating women, may benefit from DHA-fortified foods (some breakfast bars and soymilk) and microalgae-derived DHA supplements, which are well absorbed and positively influence blood levels of DHA, and also EPA through retroconversion.

Calcium

Calcium intakes of lacto-vegetarians are similar to, or may be higher than, those of nonvegetarians, whereas intakes of vegans tend to be lower than both groups and may fall below recommended intakes (see also Table 1). Vegans generally require calcium-fortified foods such as fruit juices, soy and rice milk, and breakfast cereals to meet their calcium needs. The use of herbal seasonings rather than salt will diminish the urinary calcium losses associated with a high-sodium intake. Fruits and vegetables, rich in potassium and magnesium, will produce a high renal alkaline load, which offsets the calcicuric effect of a high renal acid load associated with a diet rich in meat, dairy products, and grains. Greens that are low in oxalates (bok choy, broccoli, Chinese cabbage, and collards) and fruit juices fortified with calcium citrate malate are good sources of highly bioavailable calcium (50%–60% for the greens; 40%–50% for the juices), whereas calcium-set tofu, cow’s milk, and soy milk fortified with calcium carbonate have good bioavailability of calcium (30%–35%); calcium in sesame seeds, almonds, and dried beans has about a 25% bioavailability. Calcium absorption is considerably reduced by oxalates (spinach, Swiss chard) and phytates (nuts, whole grains).

Iron

Vegetarians often have an iron intake that is similar to or slightly better than that of nonvegetarians (see Table 1), so the issue of iron adequacy is really one of iron bioavailability. Incidence of iron-deficiency anemia is common among vegetarians and nonvegetarians alike. Although vegetarian adults have lower iron stores than nonvegetarians, their serum ferritin levels are usually within the normal range. Nonheme iron is sensitive to both inhibitors and enhancers of iron absorption. Inhibitors of iron absorption include phytates, calcium, and the polyphenolics in tea, coffee, herb teas, and cocoa. Vitamin C and other organic acids found in fruits and vegetables substantially enhance nonheme iron absorption and reduce the inhibitory effects of phytate. Soaking and sprouting beans and grains as well as leavening of bread can diminish phytate levels and enhance iron absorption. Whereas many studies of iron absorption have been short term, there is evidence that long-term adaptation does occur, involving both increased absorption and decreased losses.

Zinc

Although overt zinc deficiency has not been seen in Western vegetarians, their zinc intakes may be marginal or fall below recommendations (see Table 1). In addition, zinc bioavailability from vegetarian diets is lower than from nonvegetarian diets, mainly due to their higher phytic acid content. With vegetarians consuming diets rich in unrefined grains, nuts, and legumes, their zinc requirements may exceed the RDA. Due to limitations in evaluation of marginal zinc status, it is not possible to determine the possible effect of lower zinc intake by vegetarians. Organic acids, such as citric acid, and food preparation techniques, such as soaking and sprouting beans, grains, and seeds as well as leavening bread, can increase zinc bioavailability.

Health Effects

Cardiovascular Disease

Compared with nonvegetarians, vegetarians (both lactoovo vegetarians and vegans) have a lower risk of death from ischemic heart disease, even after adjustment for body mass index (BMI) and smoking habits. A partial explanation for the reduced mortality risk may be the lower blood lipid levels typically seen in vegetarians. Based on blood lipid data in one large cohort study, the
incidence of ischemic heart disease was estimated to be 24% lower in lifelong vegetarians and 57% lower in lifelong vegans compared with omnivores. Subjects switch from their usual diet to a vegetarian diet, they typically experience a reduction in serum total and low-density lipoprotein (LDL) cholesterol levels.

Factors in a vegetarian diet that convey a beneficial effect on blood lipid levels include vegetable oils, soluble fiber, nuts, soy, and plant sterols. The consumption of fruits and vegetables, whole grains, soy protein, and nuts may also lower the risk of cardiovascular disease (CVD) by factors other than the lowering of blood lipid levels. Vegetarians also consume higher levels of flavonoids and other phytochemicals than do omnivores. These antioxidants provide beneficial cardiovascular protection, by reducing platelet aggregation and blood clotting, acting as anti-inflammatory agents, and improving vascular endothelial function. Conservative vegetarian diets have been used to successfully manage CVD risk factors. A near-vegan diet high in soy protein, soluble fiber, nuts, and phytosterols was shown to be as effective as a low-saturated fat diet plus a statin drug for lowering serum LDL cholesterol levels.

Vegetarians have a lower rate of hypertension than do omnivores. Preliminary results from the Adventist Health Study-2 cohort confirm the protective effect of a vegetarian diet, with vegans appearing to have an even lower rate of hypertension than other vegetarians. Some studies, but not all, report lower blood pressure levels in vegetarians compared with omnivores. This observation may be due in part to the lower BMI seen in vegetarians. Lower blood pressure levels may also result from the potassium, magnesium, antioxidants, dietary fat, and fiber found in vegetarian diets. Fruit and vegetable intake was responsible for about one half of the blood pressure reduction of the DASH (Dietary Approaches to Stop Hypertension) study.

Obesity

BMI values are reported to be higher in nonvegetarians compared with vegetarians for both men and women, and BMI values tend to increase as the frequency of meat consumption increases. Among vegetarians, vegans have the lowest BMI values of all vegetarians. It appears that one must follow a vegetarian diet for about 5 years before its benefits are seen. Weight management appears to be more effective when subjects choose a vegetarian diet or one containing fewer animal foods.

Diabetes

Vegetarians have significantly lower rates of developing type 2 diabetes than do omnivores. This may be partly explained by the greater BMI of omnivores compared with vegetarians. However, meat and processed meat intake alone was found to be an important risk factor for diabetes even after adjustment for BMI. In the Women’s Health Study, the authors observed positive associations between intakes of red meat and processed meat and risk of diabetes after adjusting for BMI, total energy intake, and exercise. An increased risk of diabetes was most pronounced for frequent consumption of processed meats such as bacon and hot dogs. In another large study, the relative risk for type 2 diabetes in women was increased 26% for red meat and 38% to 73% for processed meats for every serving of the meat added.

Higher intakes of plant foods, such as vegetables, whole grain foods, legumes, and nuts, but not fruit juice, have been associated with a substantially lower risk of insulin resistance and type 2 diabetes and improved glycemic control in either normal or insulin-resistant individuals. People consuming about 3 servings per day of whole grain foods are 20% to 30% less likely to develop type 2 diabetes than those who consume few whole grain foods (<3 servings per week). In the Nurses’ Health Study, nut consumption was inversely associated with risk of type 2 diabetes after adjustment for BMI, physical activity, and other factors. The risk of developing diabetes mellitus for those consuming nuts 5 or more times a week was 27% lower than those almost never eating nuts.

In a large prospective study of Chinese women, the risk of type 2 diabetes mellitus was 38% and 47% lower for those consuming a high intake of total legumes and soybeans, respectively, compared with a low intake, after adjustment for BMI and other factors. Legumes contain slow-release carbohydrate and are rich in soluble fiber, factors known to improve glycemic control.

A low-fat, fiber-rich vegan diet with a low to modest glycemic load considerably improved glycemic control in persons with type 2 diabetes mellitus, with 43% of the subjects reducing diabetes medication after 5 months. In this study, decreases in serum HbA1c levels correlated strongly with decreases in body weight.

Cancer

Vegetarians tend to have an overall lower cancer rate than does the general population. Although obesity is a significant risk factor for cancer at a number of sites, the lower BMI of vegetarians may explain some of the lower cancer risk in vegetarians compared with nonvegetarians. Data from the Adventist Health Study revealed that vegetarians had a significantly lower risk for both colorectal and prostate cancer compared with nonvegetarians, whereas there were no significant differences in risk of other cancers after controlling for age, gender, and smoking. In the UK Women’s Cohort Study, data suggested that vegetarian women have a lower risk of breast cancer than meat eaters. Within the EPIC-Oxford Study, the
incidence of all cancers combined was lower among vegetarians than among nonvegetarians, whereas the incidence of colorectal cancer was unexpectedly higher in vegetarians than in nonvegetarians.49

Although overall cancer rates of vegetarians are modestly lower than those of nonvegetarians living in the same communities, the data for specific cancers appear to be less convincing.56 Fraser50 has suggested that the term vegetarian may be too broad a descriptor since it refers to the absence of meat in the diet while allowing for a large variety of different intakes from all the other food groups. Since these other foods may influence risk of cancer and may comprise the majority of total caloric intake, they may confound analyses evaluating effects that use a simple definition of a vegetarian diet.50

Epidemiological studies have consistently shown that regular consumption of plant foods, such as fruit and vegetables, is strongly associated with a reduced risk of cancer.28,51 Fruit, vegetables, whole grains, and legumes contain a complex mixture of phytochemicals possessing potent antioxidant, antiproliferative, and cancer-protective activity.47

Fruit and vegetables, rich in fiber and vitamin C, exhibit protective activity against cancer of the lung, mouth, esophagus, colon, and stomach and to a lesser degree some other sites, whereas fruits rich in lycopene are reported to protect against prostate cancer.47 Furthermore, the regular use of legumes provides a measure of protection against stomach, prostate cancer,47 and colon cancer,21 whereas a high intake of whole grains has provided some protection against colorectal and possibly other cancers.52–54 Allium vegetables also protect against stomach cancer, whereas garlic ingestion protects against colorectal cancer. Researchers have suggested that for European populations with a low fiber intake, doubling the fiber intake could reduce the prevalence of colorectal cancer by 40%.55 Among Asians with a high-soy consumption, a decreased risk of breast cancer was observed with increased soy food intake. In contrast, soy intake was unrelated to breast cancer risk in studies conducted in low–soy-consuming Western populations.56 Among female Chinese breast cancer survivors who were followed for 4 years, soy food consumption was significantly associated with decreased risk of death and recurrence.57

The protective phytochemicals, such as flavonoids, indoles, sulfides, and carotenoids, have been shown in experimental systems to interfere with several cellular processes involved in the progression of cancer. These mechanisms include inhibiting cell proliferation, inhibiting DNA adduct formation, inhibiting phase 1 detoxification enzymes, inhibiting signal transduction pathways and oncogene expression, inducing cell cycle arrest and apoptosis, inducing phase 2 detoxification enzymes, blocking the activation of nuclear factor-κB, and inhibiting angiogenesis. The phytochemicals can display additive and synergistic effects.58 However, human population studies have not shown large differences in cancer incidence or mortality rates between vegetarians and nonvegetarians.22,50,59 Perhaps more detailed food consumption and food preparation data are needed as well as data on the bioavailability of phytochemicals.

Consumption of red meat and processed meat is consistently associated with an increase in the risk of colorectal cancer.57 Grilled, cured, and smoked meats and fish are associated with an increased risk of cancer due to the presence of polycyclic aromatic hydrocarbons and heterocyclic amines produced during their preparation.47 Meat consumption has also been linked in some studies with an increased risk of breast cancer.60 In a study in southern France, breast cancer risk increased by more than 50% for each additional 100 g/d of meat consumed.61

Osteoporosis

Cross-sectional and longitudinal population-based studies suggest no differences in bone mineral density (BMD), for both trabecular and cortical bone, between omnivores and lacto-ovo-vegetarians,62 so that the risk of bone fractures is similar for both groups.65 Although very few data exist on the bone health of vegans, some studies suggest that bone density is lower among vegans compared with nonvegetarians.64 This situation may be explained by inadequate intakes of protein and calcium in these studies, nutrients essential for bone health. Vitamin D status can also be compromised in some vegans.65 In the EPIC-Oxford study, the 30% higher risk of bone fracture in vegans appeared to be associated with a lower calcium intake.65

A widely held nutrition view states that a high protein intake, especially animal protein, produces bone resorption because of body’s need to buffer the acid load created by the high sulfur amino acid content. This could potentially lead to decreased bone density and increased fractures. Postmenopausal women with diets high in animal protein and low in plant protein had a high rate of bone loss and a greatly increased risk of hip fracture.66 However, evidence exists that low protein intakes may compromise the integrity of BMD.67 In an extensive review conducted by British researchers, a small positive association was found between increased protein intake and BMD.68 The authors also observed a slight positive effect of protein supplementation on lumbar spine BMD, although increased protein intake did not in any way influence bone fracture rates.68 More research is needed to determine the full extent of dietary protein upon the skeleton.

An increased consumption of fruit and vegetables, with their high potassium and magnesium content, provides a positive effect on the calcium economy and markers of bone metabolism.69 Femoral neck and lumbar spine
BMD of premenopausal women was about 15% to 20% higher for women in the highest quartile of potassium intake compared with those in the lowest quartile.\textsuperscript{70} Results from 2 large, prospective cohort studies suggest an inverse relationship between vitamin K (and green, leafy vegetable) intake and risk of hip fracture.\textsuperscript{71} Blood levels of undercarboxylated osteocalcin, a sensitive marker of vitamin K status, are used to indicate risk of hip fracture\textsuperscript{2} and predict BMD.

Consumption of soy appears to be favorable to bone health. Soy isoflavones have demonstrated a significant benefit on spine BMD by inhibiting bone resorption and stimulating bone formation compared with placebo.\textsuperscript{73} In a randomized controlled trial, postmenopausal women receiving the soy isoflavone genistein experienced significant decreases in urinary excretion of deoxypyridinoline (a marker of bone resorption) and increased levels of serum bone-specific alkaline phosphatase (a marker of bone formation).\textsuperscript{74}

**Comparison of Vegetarian Diets**

Because a typical lacto-ovo-vegetarian diet includes dairy and egg products, it tends to be a less restrictive diet with more food choices than a typical vegan diet. A lacto-ovo-vegetarian diet is also more calorie dense than a vegan diet so it better maintains optimal child growth and ideal childhood weight. The vegan diet, unless there is an intentional use of appropriately fortified foods, provides less amounts of dietary calcium, vitamin D, and vitamin B\textsubscript{12} (see Table 1) than a lacto-ovo-vegetarian diet, making deficiencies of these nutrients more likely. Compared with a lacto-ovo-vegetarian diet, a vegan diet is associated with less allergies (since milk and eggs are absent) and typically has a reduced saturated fat and cholesterol intake. Data from the Adventist Health Study found that compared with lacto-ovo-vegetarians, vegans were thinner, had lower blood levels of total and LDL cholesterol with a lower risk of CVD, had modestly lower blood pressure levels, and had lower incidence of stroke and diabetes mellitus.\textsuperscript{50,75}

There is a need for more data on bone health and the risk of osteoporosis in vegans. Overall, there are too few studies on vegans, and many of the studies that exist contain small sample sizes.

The consumption of a raw food diet rich in plant foods is associated with an improvement of fibromyalgia and rheumatoid arthritis symptoms, an enhanced antioxidant status and improved immune function, self-reported improvement in health and quality of life, and decreased blood pressure and blood lipid levels.\textsuperscript{76} However, those who followed a raw food diet were found to have inadequate intakes of calories, protein, vitamin D, vitamin B\textsubscript{12}, calcium, and zinc.\textsuperscript{77}

**Conclusions**

Appropriately planned vegetarian diets are healthful and nutritionally adequate and are beneficial in the prevention and treatment of certain chronic diseases. Poorly planned vegetarian diets can be deficient in vitamin B\textsubscript{12}, calcium, vitamin D, zinc, iron, and long-chain ω-3 fatty acids. Vegetarians need to incorporate into their diet foods that provide adequate levels of these vitamins, minerals, and ω-3 fatty acids. Tables outlining the foods and fortified products that contain significant levels of these nutrients are available.\textsuperscript{6,78} There is a need for additional studies of the association between the spectrum of types of vegetarian diets and risk of chronic disease.

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