

Plant-based diets and bone health

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ABSTRACT

The vegetarian tradition has very ancient origins. This type of nutritional pattern first “appeared” in the countries of the Far East. Switching from the typical modern Western diet to a vegetarian diet offers benefits, but this does not necessarily mean that such a diet can be considered “ideal” for all aspects of individual health.

Thus, while a vegetarian/vegan diet plays a significant role in optimizing several specific issues related to metabolic and chronic disorders, there are controversial data regarding its potential risks to bone tissue. Thus, this review examines the potential issues associated with this type of nutritional pattern and bone health.

KEYWORDS

Skeleton, vegetarian, vegan, protein, minerals.

Introduction

The vegetarian tradition has very ancient origins. This type of nutritional pattern first “appeared” in the countries of the Far East. In fact, Eastern religions, such as Buddhism and Hinduism, urge their followers to “convert” to vegetarianism, which is seen as a path to spiritual realization. Similarly, the idea that eating animal food contaminates and makes the human soul “ugly” came to Europe from the East.

Illustrious people of the ancient world followed vegetarian diets, the most famous ones including Pythagoras, Plutarch, Seneca, Plato and Leonardo da Vinci.

In the Middle Ages, too, it seems that the vegetarian diet, as opposed to an omnivorous or carnivorous one, was felt to enhance “spiritual purity”, with Catholic monks, who renounced meat eating, preferring to consume exclusively frugal meals in order to dominate their carnal instincts.

The term “vegetarian” was coined only in 1847 by a group of people who later founded, in Great Britain, the Vegetarian Society, and it simply referred to those who did not eat meat, poultry or fish, without alluding to other specific nutritional behaviors.

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The Italian vegetarian association, named the Vegetarian Society, was founded on 12 September, 1952 in Perugia. Its founding father was Aldo Capitini, great Italian intellectual and supporter of peace and non-violence, famous for “importing” the thought of Gandhi into Italy.

There are several different plant-based diets, as shown in Table I.

Switching to a vegetarian diet from the typical modern Western diet offers benefits, but this does not necessarily mean that such a diet can be considered “ideal” for all aspects of individual health. A truly ideal diet should be based on a comprehensive set of scientific data that confirms its nutritional correctness, safety, and health benefits. Moreover, an ideal diet should be easy to plan and follow, based on “real” foods, eco-

Table I Plant-based diets and their variations.

Lacto-vegetarian diet	This is a diet based on plant products that includes, however, milk and its derivatives
Semi-vegetarian diet	This type of diet is based on plant products with some groups of animal products
Lacto-ovo-vegetarian diet	This is a diet based on plant products that includes the consumption of eggs, milk and their derivatives
Fruitarian or fruit-eating diet	This is a diet of solely fruit (and vegetables), fresh or processed
Pesco-vegetarian diet	This type of diet excludes meat (white and red) but includes fish and vegetable products
Macrobiotic diet	This diet eliminates all types of animal foods, although in some the consumption of fish is envisaged. Central to this diet are “organic” foods not that have not been treated or processed
Vegan diet	This is a diet that completely excludes all animal products, even derivatives such as milk, honey and eggs

nomically accessible, and environmentally sustainable, that is, compatible with the needs of our planet.

However, while a vegetarian/vegan diet plays a significant role in optimizing several specific issues related to metabolic and chronic disorders, there is controversial data regarding the risks it potentially poses to bone tissue.

On the other hand, numerous scientific studies have demonstrated that a completely plant-based diet can provide all the necessary nutrients. Therefore, providing it is well balanced, such a diet should theoretically ensure good nutritional status and consequently bone health. This paper examines, from the perspective of bone health, the potential issues surrounding this type of nutritional pattern.

Plant-based diets

Many factors motivate individuals to adopt vegetarian or vegan diets, ranging from ethical concerns to health considerations. One of the primary ethical motivations is to preserve animal well-being. Increased awareness leads many to seek a diet that, aligned with values of compassion and non-violence, minimizes harm to animals. In addition to ethical reasons, environmental concerns also play a significant role. Plant-based diets are known for their lower environmental impact, as they require fewer natural resources and result in lower emissions of greenhouse gases compared with diets that include meat. This sustainable approach to nutrition addresses global issues like deforestation, biodiversity loss, and water scarcity.

Scientific research provides substantial evidence supporting the advantages, in terms of health benefits, of vegetarian and vegan diets. With regard to cardiovascular health, studies like those published in the *Journal of the American Heart Association* have shown that these diets can lead to lower levels of LDL cholesterol and improved blood pressure, significantly reducing the risk of heart disease. From the perspective of weight management, research published in the *Journal of General Internal Medicine* indicates that plant-based diets help individuals to maintain a lower body mass index (BMI) and reduce the risk of obesity ^[1].

Diabetes prevention is another critical health benefit. A comprehensive review suggests that vegetarian and vegan diets can lower the risk of developing type 2 diabetes by enhancing insulin sensitivity ^[2]. As for cancer prevention, the *American Journal of Clinical Nutrition* has found that high intakes of fruit, vegetables, and fiber, typical of vegetarian diets, are associated with lower risks of certain cancers, particularly those of the digestive system ^[3]. On the other hand, plant-based diets need careful planning to ensure that they provide all the nutrients essential for maintaining strong bones. Key nutrients include calcium, vitamin D, and magnesium, which are vital for bone density and overall skeletal health.

Caloric intake and nutritional status

The relationship between caloric intake in plant-based diets and bone health is nuanced, mainly due to the low caloric

density of many plant foods. While this lower caloric density is an advantage for managing and preventing metabolic disorders such as diabetes and cardiovascular diseases, it presents challenges for bone health, especially for individuals who tend to have a naturally lean physique or who have a high basal metabolic rate and high energy expenditure.

Plant-based diets are rich in nutrients beneficial for overall health ^[4-8] but typically do not provide sufficient calories to meet the energy requirements of some individuals. This can result in a lower BMI and potentially increase the risk of reduced bone density, osteopenia, and osteoporosis. Maintaining adequate caloric intake is crucial for bone health as it supports the preservation of both bone and muscle mass, which are directly related to bone strength and overall skeletal stability ^[9].

Additionally, sarcopenia, the loss of muscle mass and function, is closely linked to bone health since it can increase the risk of falls and fractures, further compounding the health risks associated with inadequate bone density.

Calcium

Calcium is essential for bone health, playing a critical role in building and maintaining strong bones and teeth. In plant-based diets, ensuring adequate calcium intake is vital, as these diets do not include traditional dairy sources. Instead, calcium can be sourced from fortified plant “milks” and juices, which often provide similar amounts per serving as dairy milk. Leafy green vegetables like kale, bok choy, and broccoli are good sources of calcium and are well absorbed by the body. Additionally, tofu and tempeh, when prepared with calcium sulfate, serve as excellent sources of this mineral. Almonds and sesame seeds are also significant sources of calcium and can be easily incorporated into meals. Beyond these, dried fruits such as figs provide a notable amount of calcium. Many breakfast cereals and snack bars are fortified with calcium, offering an easy option to increase intake, particularly useful during busy mornings or for snacks. However, it is important to remember the potential lower bioavailability of calcium in all the above-mentioned foods.

Thus, while it is important to increase calcium intake when on a plant-based diet, it is equally crucial to enhance its absorption. Vitamin D, for instance, plays a key role in calcium absorption, and while sunlight is a primary source, fortified plant “milks” and cereals can also provide vitamin D. Managing intake of sodium and caffeine is important too, as high levels can increase calcium excretion. Furthermore, some plant-based foods contain phytates and oxalates that can inhibit calcium absorption, but cooking methods such as steaming and boiling can reduce the effects of these compounds.

For those on plant-based diets, strategic dietary planning is essential in order to make sure their calcium needs are met. This means not only selecting the right foods but also considering timing of consumption and dietary combinations, so as to maximize nutrient absorption. Regular dietary assessments can help ensure that calcium intake is adequate to support bone health effectively, mitigating potential risks associated with lower bone density and ensuring overall skeletal health.

Studies have shown that vegan and vegetarian diets can often lead to lower calcium intake compared with omnivorous diets ^[10,11]. A systematic review and meta-analysis that compared calcium intake across these diets found that vegans generally consume less calcium than both vegetarians and omnivores. Vegetarians, however, did not show a significant difference in calcium intake when compared with omnivores. This suggests that while vegetarian diets can provide adequate calcium, vegan diets might require more attention to ensure sufficient calcium intake to maintain bone health ^[12].

Moreover, individuals on vegan diets need to be particularly vigilant about their calcium sources. Indeed, it is recommended that plant-based diets include a variety of calcium-rich foods such as fortified plant “milks”, leafy green vegetables, and tofu made with calcium sulfate. Despite these available sources, the overall lower calcium intake in vegan diets underscores the importance of careful dietary planning to prevent potential deficiencies that could affect bone health ^[13].

Magnesium

Much like calcium, magnesium is essential for bone health as it plays a critical role in building and maintaining a healthy bone matrix and ensuring that vitamin D functions effectively, promoting optimal calcium absorption.

Research indicates that individuals following vegan and vegetarian diets often need to pay particular attention to their magnesium intake. Plant-based diets, which are rich in fruit, vegetables, whole grains, and nuts, generally provide beneficial amounts of magnesium. However, the overall nutrient balance needs careful management to prevent deficiencies. A systematic review highlights that while these diets are typically higher in magnesium compared with diets that include meat, the variability in food choices within vegan and vegetarian populations can lead to inconsistent magnesium intake levels ^[14]. This inconsistency might be due to different food preferences and dietary habits within the vegetarian and vegan populations, emphasizing the importance of balanced diet planning. Moreover, a study conducted as part of the NuEva research project highlighted the importance of carefully monitoring nutrient intake among vegans and vegetarians ^[15]. It noted that although plant-based diets are generally nutrient-dense, individuals following these diets need to plan their meals thoughtfully to avoid potential deficiencies, including magnesium deficiency. This finding reinforces the need for dietary diversity and possibly the inclusion of fortified foods or supplements to ensure adequate nutrient intake ^[16].

To maintain sufficient magnesium levels in plant-based diets, it is important to include a variety of magnesium-rich foods. Leafy greens such as spinach and Swiss chard, nuts like almonds and cashews, legumes including black beans and lentils, and whole grains such as quinoa and brown rice are all excellent sources. Tofu, especially when set with magnesium chloride (nigari), also contributes to magnesium intake.

However, the bioavailability of magnesium can be affected by the presence of phytates in the diet, which can bind minerals and reduce their absorption.

To enhance magnesium absorption, it is beneficial to employ methods such as soaking and sprouting grains and legumes to reduce phytate levels. It is also important to balance the intake of other minerals like calcium and potassium, as they interact with magnesium and can affect its retention and absorption ^[17,18].

For those following a plant-based diet, strategic dietary planning is essential. This includes not only choosing a variety of magnesium-rich foods but also considering fortified foods or supplements if necessary.

Phosphorus

Phosphorus is integral to bone health, much like magnesium and calcium, as it forms a critical component of bone structure and enhances the effectiveness of vitamin D, necessary for calcium metabolism. Similar to the relationship between magnesium and bone health, phosphorus works along with vitamin D to ensure proper calcium utilization, crucial for bone growth and repair.

As with magnesium, phosphorus is available in a variety of plant foods that are staples in vegan and vegetarian diets. To achieve sufficient intake, it is beneficial to incorporate diverse sources such as pumpkin seeds, lentils, almonds, and whole grains like brown rice. Tofu, especially when prepared with calcium phosphate, is also a valuable source of phosphorus.

Research on phosphorus intake in vegan and vegetarian individuals suggests that careful planning is necessary to ensure adequate levels of phosphorus, among other nutrients. Studies have found that phosphorus intake through plant-based diets is usually sufficient due to the inclusion of beans, nuts, whole grains, and seeds, which are good sources of this mineral. However, the diversity in dietary choices among individuals following these diets can lead to variability in intake of nutrients, including phosphorus ^[14].

The bioavailability of phosphorus, like that of magnesium, can be impacted by dietary choices. Phytates present in plant foods can reduce the absorption of phosphorus, and techniques such as soaking and sprouting grains and legumes can enhance its bioavailability. This mirrors the approach recommended for maximizing absorption and highlights the need for careful dietary management to ensure optimal nutrient intake ^[17].

Even though plant-based diets are generally rich in phosphorus, it is still advisable for individuals following these diets to engage in strategic dietary planning to manage phosphorus intake effectively. This approach can involve choosing a variety of naturally phosphorus-rich foods and considering the use of fortified products or supplements if necessary.

Vitamin D

Vitamin D plays a crucial role in bone health by promoting calcium absorption in the gut and maintaining serum calcium and phosphate levels that are sufficient to enable normal mineralization of bone. Vitamin D is essential for bone growth and bone remodeling by osteoblasts and osteoclasts. It is estimated

that dietary sources typically account for only about 10-20% of the vitamin D required by the human body, while the majority, approximately 80-90%, is synthesized through skin exposure to sunlight. This emphasizes the importance of ensuring adequate sun exposure, especially in regions with limited sunlight, and of considering supplementation if necessary ^[19].

For vegans and vegetarians, obtaining adequate vitamin D from their diet can be challenging since the primary natural sources are animal-based, including fish oils, fortified dairy products, and egg yolks. This challenge is compounded by the fact that few plant-based foods naturally contain significant amounts of vitamin D. Some of the vegan-friendly sources include fortified plant “milks” and cereals, and certain types of mushrooms exposed to ultraviolet light to increase vitamin D levels. The risk of vitamin D deficiency can be higher in vegan and vegetarian populations, particularly in regions with limited sunlight exposure.

Recent studies highlighted that vitamin D intake and status are often lower in vegans and vegetarians than in omnivores ^[14,20]. The risk of deficiency is particularly notable in regions with limited sunlight exposure, which can lead to impaired bone mineralization and contribute to conditions such as rickets in children and osteomalacia in adults ^[14]. In more prolonged cases, it may also contribute to osteoporosis, where decreased bone density increases the risk of fractures.

To ensure adequate intake, vegans and vegetarians are often advised to regularly use vitamin D supplements, especially during the darker months at northern latitudes. Regular blood tests can help monitor levels and determine the need for supplementation.

Furthermore, lifestyle factors such as outdoor activities in sunlight can help increase vitamin D levels naturally.

The EPIC-Oxford study has reported that vegans often have lower serum levels of 25-hydroxyvitamin D compared with vegetarians and omnivores, highlighting the need for adequate dietary sources or supplementation ^[12].

Dietary sources for vegetarians include fortified foods like cereals, plant-based beverages, and orange juice. For vegans, particularly in regions like Europe where fortified foods may not be widely available, the challenge is greater. During winter months in northern countries, dietary intake might not be sufficient to maintain normal vitamin D and parathyroid hormone levels, and this can negatively affect bone mineral density ^[21].

To address these challenges, both vitamin D2 and vitamin D3 supplements can be effective. However, vitamin D3, at higher doses, may be more efficient than D2 at raising blood levels of vitamin D. It is important that vegetarians and especially vegans consider supplementation in order to reach the recommended daily amounts ^[22].

Given the crucial functions of vitamin D and the potential challenges in obtaining it from a plant-based diet alone, strategic dietary planning and possibly supplementation are vital for maintaining bone health and overall wellness in vegan and vegetarian individuals.

This consideration highlights the importance of tailored nutritional advice and planning for those choosing plant-based diets, so as to ensure they meet all their micronutrient (including vitamin D) needs.

Conclusions

Plant-based diets offer a range of health benefits and have the potential to provide all the necessary nutrients for maintaining bone health. The abundance of fruit, vegetables, nuts, and whole grains in these diets not only contributes to overall wellness, but also specifically supports skeletal integrity through nutrients like calcium, magnesium, and vitamin K1. These diets are particularly rich in dietary fiber, antioxidants, and bioactive compounds which contribute to health and prevent various chronic diseases.

However, there are critical considerations that must be addressed to optimize the nutritional adequacy of plant-based diets, especially as far as bone health is concerned. In the case of nutrients that are typically less abundant or bioavailable in plant-based diets, such as vitamin D, vitamin K2, and certain forms of calcium and magnesium, careful planning is needed to ensure the daily recommended intakes. Vegan and vegetarian individuals may face challenges in obtaining enough of these nutrients due to limited non-animal-based natural food sources.

Therefore, the adoption of a plant-based diet should be accompanied by specific patient education to ensure adequate dietary intake of these critical nutrients. Health professionals play a crucial role in this educational process, providing guidance on dietary choices and supplement use where necessary. Dietary assessments and regular monitoring can help tailor plant-based diets to individual nutritional needs, ensuring that all requirements are met to support bone health and overall well-being.

By addressing these nutritional concerns, individuals following plant-based diets can maximize the health benefits they offer while minimizing the risks associated with nutrient deficiencies. This proactive approach will help sustain the long-term health benefits of a plant-based dietary pattern, making it a viable and health-promoting option for many individuals.

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