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REVIEW

Nutrition-Based Support for Osteoporosis in Postmenopausal Women: A Review of Recent Evidence

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Abstract: Postmenopausal osteoporosis stands as the predominant bone disorder in the developed world, posing a significant public health challenge. Nutritional factors play a crucial role in bone health and may contribute to its prevention or treatment. Calcium and vitamin D, extensively studied with robust scientific evidence, are integral components of the non-pharmacological treatment for this disorder. Nevertheless, other less-explored nutritional elements appear to influence bone metabolism. This review provides a comprehensive summary of the latest evidence concerning the relationship between various nutrients, such as phosphorus, magnesium, vitamins, phytate, and phytoestrogens; specific foods like dairy or soy, and dietary patterns such as the Mediterranean diet with bone health and osteoporosis.

Keywords: postmenopausal osteoporosis, nutrition, micronutrients, bone health, dietary interventions, food components

Introduction

Osteoporosis is a chronic bone disorder characterized by compromised bone strength due to increased bone turnover and decreased bone mineral density (BMD) that predisposes individuals to a higher incidence of fractures.[1,2] As established by a World Health Organization working group in 1994, osteoporosis is defined based on BMD using T-scores and assessed through dual-energy X-ray absorptiometry (DXA).[3]

This condition can be classified into two etiological groups: primary and secondary osteoporosis, the first one an expected outcome of ageing in humans that encompasses postmenopausal osteoporosis—the most common bone disorder in the developed world.[4] It is estimated that osteoporosis affects over 200 million women worldwide, with menopausal and postmenopausal women having the highest prevalence of osteopenia and osteoporosis globally, at 42.1% and 27.4%, respectively, according to a recent systematic review.[5,6] This poses a well-defined public health problem with significant morbidity and a high healthcare, economic, and social cost.[3]

The bone tissue is dynamic, undergoing constant changes due to bone remodelling, regulated by various factors in different pathways such as calcitonin, parathyroid hormone (PTH), and estrogen—the latter being the primary hormonal regulator of osteoclastic bone resorption.[7–10] Ovarian senescence characteristic of menopause leads to a sudden drop in estrogen levels, resulting in increased bone resorption and an elevated risk of osteoporosis and fractures.[11,12]

In addition to hormonal changes, multiple factors, categorized as modifiable and non-modifiable, can affect bone mass and health. Non-modifiable factors include age, sex, race, and genetic predisposition. Modifiable factors play a crucial role in preventing and treating osteoporosis,[13,14] with smoking, physical activity, and specific nutritional factors being particularly relevant.[15–18]

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The extracellular bone matrix comprises organic and inorganic components. While the organic part consists of proteins, inorganic components include ions such as calcium, phosphorus, and magnesium.[19] Nutrients directly affect bone health when necessary for bone structure and indirectly when they improve the utilization and absorption of other nutrients involved in bone homeostasis or contribute to the regulation of calciotropic hormones.[1] Calcium and vitamin D have demonstrated significant roles in bone structure and metabolism, supported by ample scientific evidence for inclusion in osteoporosis management guidelines.[20] However, other nutrients, foods, and dietary patterns have shown some association with bone health, although many remain controversial.[21–25]

Therefore, this review aims to provide information on the latest evidence regarding nutritional support for post-menopausal osteoporosis, considering nutrients, foods, and dietary patterns.

Nutrients

Macronutrients

An adequate and balanced intake of macronutrients holds great significance in maintaining health. Associations between certain macronutrients and bone health have been observed. Table 1 provides a summarized overview of this information.

Fatty Acids

The intake of fatty acids and their plasma levels influence bone health, although they do so differently depending on the number of double bonds in their carbon chain.

A high-fat diet, particularly when rich in saturated fatty acids (SFAs), appears to have negative effects on bone through various mechanisms: the formation of complexes with calcium and other minerals in the intestine, promoting their loss through faeces; the synthesis of prostaglandins; the formation of osteoblasts (cells responsible for bone matrix production); and lipid oxidation.[1] Palmitic acid, one of the most abundant SFAs in the diet, induces apoptosis of osteoblasts and enhances the survival of osteoclasts (cells responsible for bone resorption) by preventing their apoptosis.[26] Various studies have found positive associations between lipid intake and the risk of fractures and negative associations between lipid intake and BMD.[31–34]

In contrast, polyunsaturated fatty acids (PUFAs) play a positive role in preventing and treating osteoporosis. Omega-3 fatty acids, in particular, modulate the activity of osteoclasts and osteoblasts, control inflammatory processes, and regulate calcium metabolism, making them beneficial for bone health. The role of omega-6 fatty acids needs to be clarified.[33] According to observational studies, the total intake of PUFAs appears to increase BMD and even reduce the risk of fractures.[27,28]

Consuming omega-3 fatty acids could be a prospective approach to protect against excessive bone loss. The three main omega-3 PUFAs are alpha-linolenic acid, obtained mainly from nuts such as walnuts, seeds such as flaxseed and chia, and vegetable oils such as soy or flaxseed oil; and eicosapentaenoic acid and docosahexaenoic acid, primarily found in fatty fish.[35]

Table 1 Involvement of Different Macronutrients and Dietary Recommendations in Bone Health

Macronutrient	Role in Bone Health	Dietary Recommendation
Saturated Fatty Acids	Promote the formation of complexes with calcium, leading to its elimination through faeces, and apoptosis of osteoblasts[1,26]	Limit the consumption of ultra-processed foods
Polyunsaturated Fatty Acids	Modulate the activity of osteoclasts and osteoblasts; control inflammatory processes[27,28]	Ensure proper consumption of foods rich in omega-3 fatty acids, such as walnuts or fatty fish
Carbohydrates	Hyperglycemia increases inflammation, oxidative stress, bone resorption due to acidosis, and urinary calcium excretion[29]	Recommend foods with a high glycemic index and rich in fiber, such as fruits, vegetables, and whole grains
Proteins	Provide necessary amino acids for bone remodelling and enhance calcium absorption in the intestine[1,30]	Increase protein intake above 0.8 g/kg of body weight per day if there are no contraindications

Carbohydrates

The relationship between carbohydrate consumption and osteoporosis needs to be better studied compared to other macronutrients. Elevated blood glucose concentrations are known to negatively affect bone health for various reasons: an increase in inflammation and oxidative stress, a reduction in the activity of osteoblasts, and enhanced bone resorption due to acidosis. In addition, hyperglycemia also appears to increase calcium excretion in urine and interfere with PTH and vitamin D receptors.[29] Therefore, many studies have demonstrated that diabetes has a negative impact on bone fractures, although the results regarding BMD are less clear.[36,37]

A recent study has used an index developed to assess carbohydrate quality in the diet, including different components such as glycemic control or dietary fiber. This study has shown that higher values in this index are associated with a lower risk of osteoporosis and osteopenia in postmenopausal women. Therefore, diets that reduce postprandial hyperglycemia have a positive effect on bone health. A good example is a diet rich in fruits, vegetables and whole grains.[38]

Proteins

Dietary proteins play a role in bone remodelling through various mechanisms. Firstly, they provide the amino acids to construct both bone matrix and muscle mass.[1] Additionally, they increase serum levels of insulin-like growth factor 1 (IGF-1), a hormone involved in the proliferation of osteoblasts and the renal hydroxylation of 25-hydroxyvitamin D, contributing to increased calcium absorption in the intestine.[30]

Despite this, the role of dietary proteins in bone health is controversial. Traditionally, it was assumed that dietary proteins had no effect on BMD, and even a controlled and randomized trial that studied protein supplementation for two years in postmenopausal women with adequate serum protein levels found negative effects on BMD.[39,40] However, recent longitudinal, epidemiological, and population studies on osteoporosis treatment have indicated that protein intake above the recommended daily amount (0.8 g/kg of body weight/day) can maintain BMD and reduce the risk of osteoporotic fractures in older adult patients.[41,42] Additionally, protein supplementation combined with dietary proteins reduces fracture risk in postmenopausal women diagnosed with osteoporosis.[43]

Although studies on the role of proteins in preventing osteoporosis are scarce, they play an essential role in treatment, especially proteins from dairy sources, due to their high quality and combination with vitamin D and calcium.[33]

Micronutrients

Micronutrients are the nutrients that have been most extensively studied concerning the treatment and prevention of osteoporosis. Calcium and vitamin D, as mentioned earlier, have been thoroughly researched over the years, with a significant body of literature and sufficient scientific evidence to be part of the non-pharmacological treatment for osteoporosis.[44–47] Therefore, the role of these nutrients will not be addressed in this review, which will focus on those where the evidence is less robust. Table 2 summarizes all this information.

Phosphorus

Phosphorus is one of the primary components of the bone matrix as it forms part of hydroxyapatite crystals. Alongside calcium, phosphorus makes up 65% of the inorganic matter in bone. Therefore, it is logical to think that changes in phosphorus intake or serum levels may influence bone health; however, this relationship remains controversial.[59,60]

Population surveys and clinical studies have demonstrated a very low prevalence of low phosphorus intake or low blood phosphorus levels. Generally, the population in developed countries tends to have an excessive intake of this micronutrient, especially in the form of phosphate (used as an additive in processed foods) or phosphoric acid (present in cola beverages).[23,48] This high phosphorus intake paradoxically appears to negatively affect bone health.

The importance of maintaining a calcium-phosphorus ratio equal to or greater than one has been described, and ratios lower than this may be a negative factor for bone metabolism.[61] Experimental human studies have shown that excessive phosphorus intake in women with low calcium intake is associated with increased serum PTH concentrations and bone

Table 2 Involvement of Different Micronutrients and Dietary Recommendations in Bone Health

Micronutrient	Role in Bone Health	Dietary Recommendation
Phosphorus	Important component of the bone matrix Excessive consumption, especially in populations with low calcium intake, increases PTH and bone resorption[48,49]	Limit the consumption of ultra-processed foods
Magnesium	Enzymatic cofactor in bone matrix synthesis Its deficiency alters PTH secretion, reduces vitamin D levels, and increases bone resorption[50,51]	Recommend adequate consumption of nuts and legumes
Vitamins B	Involvement in homocysteine metabolism Deficiency of B6, B9, and B12 leads to increased blood homocysteine levels, which is a risk factor for osteoporosis[52–54]	More scientific evidence needed
Vitamin C	Participation in the formation of osteoblasts, as well as in collagen synthesis[55]	Ensure proper intake of fruits and vegetables
Vitamin E	Potent antioxidant that helps control oxidative stress levels and, therefore, bone resorption[56]	Recommend the consumption of vegetable oils and seeds
Vitamin K	Essential cofactor for the gamma-carboxylation of osteocalcin and, therefore, for its activation Its deficiency increases serum levels of undercarboxylated osteocalcin, a risk factor for osteoporotic fractures[57,58]	Promote the consumption of fermented foods like cheese and ensure proper intake of fish and eggs

resorption.[48,49] Therefore, following a healthy diet with limited consumption of ultra-processed foods would favour the maintenance of an appropriate calcium/phosphorus ratio.

Magnesium

Another micronutrient that plays a significant role in bone health is magnesium, one of the most abundant cations in the body stored mainly in the bone. Magnesium has a crucial role various metabolic reactions and is an enzymatic cofactor for the normal synthesis of the bone matrix.[62,63]

According to dietary surveys, magnesium intake is lower than recommended, especially in the older population or in response to diuretics or laxative therapies.[64] This deficiency can directly affect the bone by reducing muscle stiffness, increasing osteoclasts, and decreasing osteoblasts. Indirectly, it can promote inflammation and oxidative stress, alter PTH secretion, and reduce 25-hydroxyvitamin D levels.[50,51]

There are conflicting results in studies examining the relationship between magnesium intake and bone health; however, most authors agree that low serum magnesium levels are associated with a higher risk of osteoporosis. A recent prospective study demonstrated that a higher dietary intake of this micronutrient has a protective effect on osteoporotic bone fractures, particularly in women.[51] A meta-analysis conducted in 2022 concluded that there is a significant positive association between higher magnesium intake and higher BMD in the hip.[62]

This micronutrient is mainly found in nuts and legumes, and optimizing its intake could represent an effective preventive measure for osteoporosis in individuals with a deficiency. Supplementation in the general population still raises doubts, as an intake above the recommended daily amount also appears to have detrimental effects on bone health.[65]

Vitamins B

The B vitamins are involved in the metabolism of homocysteine, an amino acid that modulates the bone remodelling process, primarily by increasing the activity and differentiation of osteoclasts.[52] Deficiency in vitamins B_6, B_9 or folate, and B_{12} lead to increased blood homocysteine levels, considered an independent risk factor for osteoporosis.[52–54] Additionally, studies have shown a positive correlation between dietary folate intake and BMD.[66]

However, the underlying mechanisms of this association are complex, and more scientific evidence is needed to assert the role of vitamin B in the treatment and prevention of osteoporosis beyond reducing blood homocysteine levels. While the relationship between B vitamins, homocysteine, and bone health is recognized, more research is needed to understand the intricate interplay and to determine the effectiveness of B-vitamin supplementation in managing osteoporosis.

Vitamin C

Vitamin C is another micronutrient involved in bone metabolism, playing a significant role in various processes affecting BMD. Firstly, it is implicated in the formation of osteoblasts through complex mechanisms—recent evidence suggests that vitamin C is involved in the genetic expression of specific genes responsible for the growth, metabolism, or death of preosteoblastic cells. Additionally, it plays a role in collagen synthesis. Vitamin C acts as a cofactor in the hydroxylation reactions of collagen fibres, playing a fundamental role in the quality of this protein.[55]

Several reviews and meta-analyses have demonstrated a positive association between higher dietary intake of vitamin C and higher proximal femur BMD in postmenopausal women, as well as a lower risk of fractures and osteoporosis.[67,68] These findings are consistent when studying the association between blood vitamin C concentration and BMD.[67] Regarding vitamin C supplementation, despite some studies showing positive results in preventing and treating osteoporosis, the evidence for a beneficial effect of supplementation in individuals without significant deficiency needs to be clarified. The considerable variability in clinical trials, with small patient groups and very different follow-up times and supplementation schemes, makes it challenging to assess its effectiveness.[69]

Although the association between vitamin C intake and BMD is complex and seems to be influenced by other factors such as estrogen hormone therapy, the intake of other nutrients like calcium, or habits like smoking, it is important to pay attention to the correct dietary intake of vitamin C through fruits and vegetables, based on the results mentioned above.[67]

Vitamin E

Vitamin E is a fat-soluble vitamin with different forms, with α-tocopherol being the most studied as it is the predominant form and appears to be the only biologically active form in humans.[70] The primary function of vitamin E is the reduction of reactive oxygen species (ROS) and various proinflammatory cytokines, making it a potent antioxidant agent.[71]

Elevated levels of ROS lead to bone loss, as oxidative stress activates the differentiation of preosteoclasts into osteoclasts, thereby increasing bone resorption, especially in postmenopausal women. These facts underscore the protective effect of antioxidant agents such as vitamin E on bone health.[56]

According to different authors, high levels of vitamin E are associated with high BMD in the spine and a low prevalence of osteoporosis. In contrast, low serum concentrations are linked to an increased risk of osteoporotic fractures.[72,73] The majority of studies examining the role of vitamin E supplementation in the prevention and treatment of osteoporosis combine this vitamin with vitamin C, another potent antioxidant, and yield positive results, demonstrating a protective effect against osteoporosis in postmenopausal women.[69,74]

The primary dietary sources of vitamin E in Mediterranean countries include vegetable oils, especially olive oil, fruits, vegetables, nuts, and seeds. Ensuring its intake to maintain adequate plasma levels of vitamin E can help prevent osteoporosis.[73]

Vitamin K

Vitamin K plays a crucial role in bone health as it is necessary for the gamma-carboxylation of osteocalcin, a protein synthesized and secreted by osteoblasts essential for the formation of hydroxyapatite crystals. The activation of osteocalcin depends on its degree of carboxylation, and vitamin K is an essential cofactor in this process.[57]

When there is a deficiency of serum vitamin K, the carboxylation capacity of osteocalcin weakens, leading to increased levels of undercarboxylated osteocalcin in serum. In observational studies, both vitamin K deficiency and undercarboxylated osteocalcin are considered risk factors for hip fractures.[58] Despite this, the role of this vitamin in the treatment and prevention of osteoporosis still needs to be defined.

Studies in recent years have reported contradictory results. The authors of a meta-analysis conducted in 2019 found no evidence that vitamin K affected BMD or the risk of vertebral fractures in postmenopausal women or those diagnosed with

osteoporosis.[75] However, there are more recent meta-analyses with positive results, concluding that vitamin K2 supplementation helps maintain and improve BMD in postmenopausal women, and reduces the incidence of fractures.[11,76]

Vitamin K2, or menaquinone, can be divided into short-chain and long-chain menaquinones. Menaquinones are primarily produced by bacteria, so the primary dietary sources of these compounds are fermented foods like cheeses, although they can also be found in fish, eggs, or liver.[57] The most significant known source of vitamin K2 is currently natto, a Japanese fermented soybean condiment that has been shown to have beneficial effects on femoral neck BMD in perimenopausal women.[77]

Other Nutritional Components

Beyond macronutrients and micronutrients, other nutritional components have or seem to have an impact on bone health.

Phytate

Phytate is a compound naturally present in foods such as legumes, cereals, and nuts, which appears to affect the decalcification process similar to that of bisphosphonates, a group of widely used medications in the prevention and treatment of osteoporosis.[78]

This nutrient has a high affinity for binding to the calcium in hydroxyapatite crystals, hindering both crystallization and redissolution and, thus, bone resorption. The impact of phytate on bone health has been demonstrated in various studies, showing a positive association between its intake and BMD in postmenopausal women.[78–80]

These findings suggest that phytic acid may play a role in preventing osteoporosis; nevertheless, prospective studies are needed to clarify the directionality of this relationship.

Phytoestrogens

Phytoestrogens are non-steroidal natural polyphenolic compounds structurally similar to endogenous steroid estrogens. They are generally classified into four main groups: isoflavones, stilbenes, coumestans, and lignans. Isoflavones are the most commonly used and studied phytoestrogens, primarily found in soy and other legumes.[81]

The leading cause of postmenopausal osteoporosis is the depletion of estrogen and its ability to suppress osteoclast activity in the resorption phase and enhance apoptosis. Phytoestrogens, although with lower affinity, bind to the same receptor as endogenous estrogens, exerting similar effects.[82] This, coupled with their antioxidant capacity, suggests a potential positive role in the bone health of postmenopausal women.[83]

Numerous animal and in vitro studies have shown that phytoestrogens reduce BMD loss by inhibiting bone resorption and promoting bone formation.[81,84] Although human research is still limited, recent systematic reviews and meta-analyses of controlled and randomized clinical trials have concluded that isoflavones could be beneficial in preserving BMD and reducing bone resorption in pre- and postmenopausal women.[85] In perimenopausal women, soy isoflavones reduced bone loss rate in the lumbar spine, according to a study by Somekawa et al, and glabrene, another isoflavone found in liquorice root, is considered a possible therapeutic alternative for osteoporosis prevention and treatment in this population.[86,87] Resveratrol, a phytoestrogen belonging to the stilbenes group found in the skin of grapes and red berries, has also been shown to improve BMD in the femoral neck and lumbar spine in postmenopausal women.[88]

Although well-designed clinical trials are needed to determine the therapeutic potential of phytoestrogens on bone health, these polyphenolic compounds are being considered as cost-effective complementary preventive and therapeutic strategies in the treatment and prevention of postmenopausal osteoporosis.[89]

Foods

Numerous studies analyze the association between the consumption of specific foods and bone mineral density and their role as potential preventive or therapeutic interventions in postmenopausal osteoporosis. Most of these foods combine various nutrients mentioned earlier in their composition, providing them with beneficial characteristics for bone health.

Dairy Products

Dairy products are undoubtedly the most studied food concerning bone health, as they contain essential nutrients in preventing and treating osteoporosis: calcium, vitamin D, and dairy proteins. They also contain probiotics and dairy peptides that play a beneficial role in bone health.

Certain phosphopeptides derived from casein, the most abundant protein in milk, appear to increase calcium absorption by preventing its precipitation in the intestine. Moreover, they positively interfere with the proliferation, differentiation, and mineralization of human osteoblasts.[90,91]

On the other hand, probiotics present in fermented dairy products (or other fermented products like kefir) play a modulating role in the microbiota, which is increasingly recognized as a determinant of bone health.[92] According to scientific studies in humans, probiotics influence the levels of 25-hydroxyvitamin D and calcium absorption, slightly reducing bone loss in postmenopausal women, similar to the observed effect with calcium and vitamin D supplements.[93] However, many aspects remain to be defined, such as the types and doses of probiotics in terms of efficacy and tolerance, the duration of administration, or their role in fracture risk.

All these nutritional components make milk an important food for bone health. Nevertheless, the scientific literature remains heterogeneous on this matter, and two recent meta-analyses concluded that higher dairy consumption does not have a clear association with the risk of hip fracture or osteoporosis.[94,95]

Soy

There are also numerous scientific studies regarding soy and bone mass. Soy is an essential source of isoflavones and vitamin K. Both nutrients, as explained earlier, have shown beneficial effects in preserving BMD and, therefore, in the prevention and treatment of osteoporosis.

When studying soy as a food, observational studies have demonstrated that higher consumption is associated with a lower risk of bone fractures in postmenopausal women.[87] Therefore, its consumption as a legume source would be beneficial for preventing osteoporosis and as a complementary strategy.

Green Tea

For the past few decades, various studies have examined the relationship between green tea consumption and BMD and osteoporosis, as this beverage contains some nutrients beneficial to bone health. Firstly, green tea contains polyphenols, antioxidant agents that can protect osteoblasts from oxidative stress, thereby preserving BMD. Secondly, green tea contains isoflavones, which, as described earlier, have estrogenic effects and may help preserve BMD by reducing bone resorption in postmenopausal women.[96]

While some studies do not report any association between green tea and BMD, many others demonstrate a positive association.[97] Two meta-analyses of observational studies concluded that tea consumption could increase BMD and decrease the risk of osteoporosis.[98,99] However, it appears that this beneficial effect is lost if tea consumption is high (a recent study sets the limit at 5 cups per day) due to the presence of caffeine, that at specific doses it could counteract the effects of polyphenols and isoflavones.

Caffeine appears to promote bone loss through different molecular pathways. First, caffeine is a purine-like compound and may act as an antagonist of adenosine by competitive inhibition of its A_2 receptors, resulting in inhibition of bone formation and activation of bone resorption. On the other hand, caffeine is known to have effects on calcium metabolism, increasing its urinary excretion, and on vitamin D metabolism, inhibiting the activity of its receptor and causing activation of osteoblasts.[100,101]

Therefore, moderate consumption of green tea could help prevent and treat the characteristic decrease in BMD associated with osteoporosis.

Dietary Patterns

Mediterranean Diet

Mediterranean diet (MD) benefit people's health. Its role has been primarily studied in cardiovascular diseases; however, there are other metabolic diseases in which this dietary pattern can play a significant role in prevention and treatment.[102]

Osteoporosis is one such condition where the MD appears to have beneficial effects. Despite its variable prevalence in different European Union countries, it has been observed to be lower in the Mediterranean region. Various studies have demonstrated that higher adherence to the MD is associated with higher BMD and a lower risk of fractures.[103–105] Additionally, a study analyzing calcium intake in postmenopausal women showed that higher adherence to this dietary pattern is related to a higher daily calcium intake.[106]

The MD is characterized by a high and varied intake of fruits, vegetables, legumes, cereals, and nuts; eggs, fish, and white meat are the primary protein sources, and extra virgin olive oil is the primary lipid source. Additionally, there is a significant presence of dairy products. As developed throughout this review, these food groups are important sources of nutrients with beneficial properties for bone health: fruits and vegetables contain significant amounts of vitamins, minerals, and other antioxidants like carotenoids; legumes, cereals, and nuts contain phytate and phytoestrogens in the case of legumes; fatty fish and some nuts are rich in omega-3 fatty acids; and dairy products provide calcium and vitamin D. Olive oil has also been shown to be beneficial in preventing bone mass loss due to its high polyphenol content.[107] All of this highlights the significant role of the MD in the prevention and pathogenesis of osteoporosis, making adherence to it an important strategy to consider.

Dietary Inflammatory Index

Inflammation is related to bone remodelling and could be involved in the pathophysiology of postmenopausal osteoporosis, as some proinflammatory cytokines that regulate bone resorption have been described to be elevated due to estrogen deficiency. Different factors, including dietary factors can modify this inflammation.[108]

A tool called Dietary Inflammatory Index (DII) was developed to assess the inflammatory properties of the diet, through which an individual's inflammation levels can be assessed based on their dietary habits.[109] It is known that a proinflammatory diet induces low-grade inflammation and elevated inflammatory biomarkers such as C-reactive protein.[110] Some proinflammatory dietary factors include refined carbohydrates, processed meats, or foods rich in SFA. In contrast, anti-inflammatory dietary factors include vegetables, whole grains, olive oil, or foods rich in unsaturated fatty acids, flavonoids, vitamins, and minerals.[111]

Numerous studies have been conducted using this index to investigate the association between the inflammatory burden contributed by diet and bone health. In postmenopausal women, the results are positive: higher DII scores are associated with a greater risk of osteoporosis, lower BMD, and a higher risk of fractures.[108,112,113] These findings confirm the importance of diet in preventing and treating osteoporosis.

Conclusion

Due to the high prevalence of osteoporosis in postmenopausal women, many authors have focused their efforts on identifying preventive and therapeutic strategies alternative to pharmacological treatment that can improve the bone health of this population. Among the most studied strategies is nutrition.

The relationship between nutrition and osteoporosis has been investigated at different levels: individual nutrients, foods as a combination of nutrients, and dietary patterns as a combination of foods. Promising results have been obtained at all these levels. Although many of the findings are preliminary, and further research is needed on mechanisms of action, dosage, or supplementation duration, nutrition plays a crucial role in bone health, with many of its components having a significant impact on bone health. Figure 1 summarizes the participation of the different foods, and the nutrients they contain, discussed in the review on bone health. Those that positively influence bone health are represented in green and those that negatively influence bone health are represented in red.

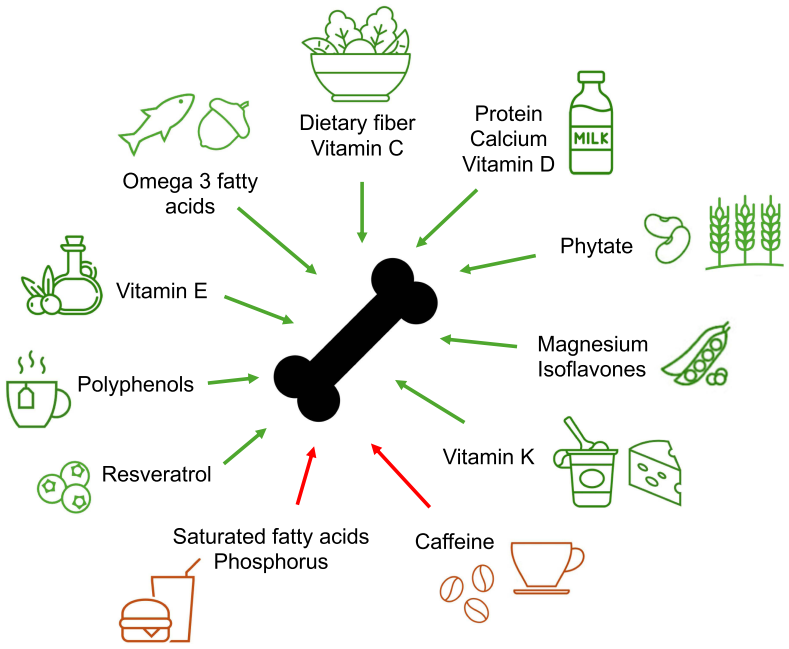

Figure 1 Implication of different foods and nutrients on bone health.
Abbreviations: BMD, bone mineral density; DII, Dietary Inflammatory Index; DXA, dual-energy X-ray absorptiometry; IGF-1, insulin-like growth factor 1; MD, Mediterranean diet; PTH, parathyroid hormone; PUFA, polyunsaturated fatty acids; ROS, reactive oxygen species; SFA, saturated fatty acids.

However, the dietary matrix presents some complexity due to the interactions between different nutrients. Therefore, it would be interesting to design and study dietary patterns focused on bone health that can prevent osteoporosis from an early age and even serve as part of the treatment once the disease is established.

Currently, based on the available scientific evidence, it seems reasonable to recommend, both for preventive and therapeutic purposes, a varied diet based on the Mediterranean diet pattern. This diet is rich in fruits and vegetables, legumes, fatty fish, whole grains, dairy, nuts, and olive oil. Additionally, limiting the consumption of ultraprocessed products and avoiding excessive caffeine intake is crucial.

Disclosure

The authors report no conflicts of interest in this work.

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