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Recommendations and metaanalyses

Dietary recommendations in the prevention and treatment of osteoporosis

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ABSTRACT

Introduction: This article presents the initial recommendations of the French Rheumatology Society (*Société Française de Rhumatologie* – SFR) and the Osteoporosis Research and Information Group (*Groupe de Recherche et d'Informations sur les Ostéoporoses* – GRIO) on the role of diet in the prevention and treatment of osteoporosis.

Methods: The recommendations were produced by a working group composed of rheumatologists, physician nutrition specialists and a geriatrician. Fifteen (15) questions pertaining to "daily practices" were preselected by the working group. For the literature review, the working group focussed mainly on the effects of diet on bone mineral density (BMD) and fractures, and primarily on meta-analyses of longitudinal studies and dietary intervention studies.

Results: A Mediterranean-type diet and the daily consumption of 2 to 3 dairy products are recommended. Together, these provide the calcium and "high quality" protein required to maintain a normal calcium-phosphorus balance and bone metabolism, and are associated with lower fracture risk. Conversely, unbalanced Western diets, vegan diets, weight-loss diets in non-overweight individuals, alcohol consumption and daily consumption of sodas are advised against. In terms of the beneficial effects on bone mineral density and fracture risk, current scientific data are either insufficient or too divergent to recommend increasing or restricting the consumption of tea or coffee, vitamins other than vitamin D, vitamin D-enriched or phytoestrogen-rich foods, calcium-enriched plant-based beverages, oral nutritional supplements, or dietary sources of prebiotics and probiotics.

Conclusions: These are the first set of recommendations addressing the role of diet in the prevention and treatment of osteoporosis. More research is necessary to direct and support guidelines.

1. Introduction

Dietary considerations are common among patients with osteoporosis. Additionally, a balanced diet is a major determinant of bone health. With the progress of scientific knowledge and changes in dietary habits – often influenced by contradictory messages that are a mixed bag of myths and actual scientific data –, new questions are emerging.

Nowadays, patients want more detailed information on the role of diet and diet regimens in the prevention and management of osteoporosis.

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We have therefore drawn up a list of recommendations for healthcare professionals, addressing the role of diet in the prevention and treatment of osteoporosis. The proposed recommendations were produced with the support of the French Rheumatology Society (SFR), the Osteoporosis Research and Information Group (GRIO) and experts in nutrition.

2. Objectives and methods

This initial set of recommendations is intended for healthcare professionals who see patients with queries on the role of nutrition in the prevention and treatment of osteoporosis. The recommendations were drawn up by a working group set up by the SFR and the GRIO, comprising 6 senior rheumatologists, 4 junior rheumatologists, 2 experts in nutrition and 1 geriatrician, who met on several occasions for that specific purpose. The recommendations are based on a shortlist of 15 practical questions selected by the working group and a partner patient from among those that are most frequently raised by patients. Four (4) groups were formed to respond to the 15 questions (3 or 4 questions per group), and a junior rheumatologist, acting under the supervision of 2 or 3 senior rheumatologists, was assigned to each group. Two (2) Study Coordinators (EB and JP) coordinated the groups' work and drafted the final version of the recommendations. The bibliographic research was conducted by the 4 junior rheumatologists and the articles they compiled were reviewed with their senior counterparts with a view to selecting the most relevant literature addressing the questions raised. The literature review focussed primarily on the body of meta-analyses of observational studies, and the rare intervention studies with BMD or fracture data addressing the questions of interest. Several joint meetings were then organised with the groups to discuss and validate the selected literature. Each group then drafted the questions before submitting them to the working group for review. When several meta-analyses on the same topic were found, all of them were taken into account in the recommendations and/or summarised in a table showing the fracture data. When the data in the literature were found to be lacking, the recommendations were based on the level of professional consensus, considering current practices and experts' opinions. The recommendations were graded based on the level of evidence of the literature, in accordance with the methodology proposed by the French National Authority for Health (*Haute Autorité de Santé* - HAS) [1].

The recommendations were then reviewed by a multidisciplinary reading committee composed of rheumatologists, experts in nutrition, a dietician and a geriatrician. Their comments were taken into account in drafting the final version of the recommendations. The members of the working group then voted on each recommendation in the final version, using a scale ranging from 0 (totally disagree) to 10 (fully agree).

These recommendations are not meant to cover all specific cases, or to relieve physicians of their responsibility to their patients.

3. Results

3.1. What are the expected benefits of the Mediterranean diet for bone health?

Traditionally, the Mediterranean diet is composed mainly of fruit and vegetables, legumes, cereals and olive oil. Dairy products – mainly fermented – are consumed daily (once or twice a day), fish at least twice a week, and meat only occasionally. The Mediterranean diet is rich in antioxidant micronutrients, vitamins C and E, carotenoids and polyphenols, and sometimes Omega-3 fatty acids. This diet has been associated with a wide range of benefits for cardiovascular health and its related risk factors, including obesity, hypertension, metabolic syndrome, dyslipidaemia and diabetes. It is also associated with less age-related cognitive dysfunction and lower incidence of neurodegenerative disorders [2]. Regarding bone health, a meta-analysis reported a positive association between high adherence to the Mediterranean diet (*vs.* low adherence) and BMD at the lumbar spine (mean difference (MD = 0.12 g/cm^2, CI95% = 0.06–0.19), femoral neck (MD = 0.10 g/cm^2, CI95% = 0.06–0.15) and total hip (MD = 0.11 g/cm^2, CI95% = 0.09–0.14) in men and women aged 20 to 79 years [3]. Recent publications have all reported a positive association between Mediterranean diet adherence scores and lower risk of hip fractures in men and women (Table 1) [3–10].

Conversely, in another meta-analysis, a Western-type diet – which is rich in red meat, refined foods, sugar-sweetened drinks and processed foods – was found to be associated with lower BMD and higher fracture risk compared to the Mediterranean diet (Table 1) [7].

Recommendation [B – scientific assumption]
A Mediterranean-type diet is associated with better bone health. It is therefore recommended for patients with osteoporosis, or in the prevention of osteoporosis.

3.2. Are vegetarian and vegan diets harmful to bone health?

Restrictive diets are, by definition, diets that exclude certain types of food. Currently, the most popular restrictive diets are vegetarian diets – which exclude all animal products – and vegan diets – which exclude all animal products, plus honey, as well as the use of non-dietary animal products (e.g., leather, wool, and silk). Vegan diets are poor in calcium, proteins and micronutrients, such as vitamins B2, B3, B12 and D, iodine, zinc, potassium and selenium [11]. Vegetarian diets exclude all animal flesh (meat, fish), but not eggs and dairy products.

In a meta-analysis, lower lumbar spine and femoral neck BMD values were reported in vegetarians and vegans compared to omnivores (e.g., at the lumbar spine, in vegans, MD = –0.070 g/cm^2, CI95% = –0.116, –0.025, and in vegetarians, MD = –0.023 g/cm^2, CI95 = –0.035, –0.010 [8]. In that same study, lumbar spine and femoral neck BMDs were found to be lower in vegans than in vegetarians. Lastly, fracture risk was 44% higher in vegans than in omnivores. A 25% increase in fracture risk was also observed in vegetarians, but the association was not statistically significant (Table 1) [8]. It is important to point out that, in that meta-analysis, no adjustments were made for weight, or calcium or protein intake.

In the EPIC-Oxford cohort, after adjusting for calcium and protein intake, only vegans exhibited an increase in fracture risk – especially at the hip – compared to omnivores (fracture risk multiplied by 2.31) [9]. In the Adventist Health 2 cohort, only vegan women exhibited a 55% increase in fracture risk at the hip, but this heightened risk was not observed in vegan women on calcium supplementation alone or combined with vitamin D (Table 1) [10].

Recommendation [B – scientific assumption]
Vegan diets, and to a lesser extent, vegetarian diets, are associated with poorer bone health. Vegan diets should therefore be avoided in patients with osteoporosis, or in the prevention of osteoporosis. In vegans, an adjustment of calcium intake should be systematically proposed.

Table 1
Fracture risk by main types of diet.

Diet	Study	Population	Hip fractures	All fractures
Mediterranean diet (MD)	Meta-analysis, Malmir et al. [3]	351,625 participants, Aged 13 to 80 years	↓ by 21% with high adhesion to the MD: RR (CI95%) = 0.79 (0.72, 0.87)	
	EPIC cohort [4]	188,795 participants (139,981 women), Mean age 48.6 years	↓by 7% per 1-point ↑ (0-10) in MD adhesion score: HR (CI95%) = 0.93 (0.89, 0.98)	
	CHANCES study [6]	140,775 participants (116,176 women), Aged ≥60 years	↓ by 4% per 2-point ↑ (0-10) in MD adhesion score: HR (CI95%) = 0.96 (0.92, 0.99)	
Western diet (WD)	Meta-analysis, Denova-Gutiérrez et al. [7]	122,061 participants, Aged >50 years		↑ by 10% in men with unbalanced (vs. balanced) WD: (M) OR (CI95%) = 1.10 (1.02, 1.19) (W) OR (CI95%) = 1.08 (1.00- 1.17)
Vegetarian diet	Meta-analysis, Iguacel et al. [8]	37,134 participants, Aged 25 to 80 years		No ↑ in risk (versus omnivores): RR (CI95%) = 1.25 (0.92, 1.71)
	EPIC-Oxford cohort [9]	34,696 participants, Aged 20 to 89 years	↑ by 25 % (versus omnivores): HR (CI95 %) = 1.25 (1.04, 1.50)	↑ by 9 % (versus omnivores): HR (CI95 %) = 1.09 (1.00, 1.19)
	Adventist Health Study 2 [10]	34,542 participants (18,712 women), Aged >45 years	No significant ↑ in risk (versus omnivores) in women and men: - Semi-vegetarians: HR (CI95 %) (W) = 0.99 (0.64, 1.53); (M) = 0.79 (0.42, 1.48) - Pescetarians: HR (CI95 %) (W) = 1.20 (0.81, 1.78); (M) = 0.81 (0.50, 1.32) - Lacto-ovo vegetarians: HR (CI95%) (W) = 1.17 (0.91, 1.50); (M) = 1.11 (0.81, 1.51)	
Vegan diet	Meta-analysis, Iguacel et al. [8]	37,134 participants, Aged 25 to 80 years		↑ by 44 % (versus omnivores): RR (CI95 %) = 1.44 (1.05, 1.98)
	EPIC-Oxford cohort [9]	34,696 participants, Aged 20 to 89 years	Risk multiplied by 2: HR (CI95%) = 2.31 (1.66, 3.22)	↑ by 43 % (versus omnivores): HR (CI95 %) = 1.09 (1.20, 1.70)
	Adventist Health Study 2 [10]	34,542 participants (18,712 women), Aged >45 years	↑ by 55% in women: HR (CI95%) = 1.55 (1.06, 2.26) No ↑ in risk in M: HR (CI95%) = 1.01 (0.61, 1.68)	

Semi-vegetarians: consume meat and fish < 1 × /week; Pescetarians: include dairy products, eggs and fish in an otherwise vegetarian diet; Lacto-ovo vegetarians: include dairy products and eggs in an otherwise vegetarian diet. (M) Men; (W) Women.

3.3. How do voluntary weight-loss diets affect bone health?

The purpose of weight-loss diets is to induce weight loss by restricting daily calorie intake (CR, calorie restriction).

The main studies on the topic investigated weight loss and BMD in overweight or obese individuals. Roughly speaking, a 10% loss in weight leads to a 2% loss in bone mass. In a meta-analysis including both overweight and obese individuals, moderate bone loss was found at the total hip, but not at the lumbar spine [12]. In overweight or obese individuals, physical activity or calcium supplementation combined with a weight-loss diet seems to curb bone loss [13,14].

In a randomised trial investigating the effect on bone health of prolonged CR (–25% over 24 months) compared to unrestricted calorie intake in young, non-obese individuals (mean age: 37.9 years; mean BMI: 25.1 kg/m^2), significant bone loss was found in the CR group at the lumbar spine (-0.013 ± 0.003 *vs.* 0.007 ± 0.004 g/cm^2; $P < 0.001$), femoral neck (-0.015 ± 0.003 *vs.* 0.005 ± 0.004 g/cm^2; $P = 0.03$) and total hip (-0.017 ± 0.002 *vs.* 0.001 ± 0.003 g/cm^2; $P < 0.001$) [15]. Physical activity was identical in both groups at the outset but, at 12 and 24 months, the reduction in physical activity was significantly greater in the CR group than in the unrestricted group.

Literature investigating fracture risk is less abundant. The impact of CR on fracture risk seems to vary according to age, other factors affecting bone health, BMI and the characteristics of the diet being followed (most notably deficiencies in calcium and protein intake). Nevertheless, the risk of hip fractures may be higher in patients who lost weight than in those whose initial weight remained unchanged. In a meta-analysis involving 85,592 overweight, obese and non-obese individuals (1,374 hip fractures), the risk of hip fractures increased by 84% in those who lost the most weight compared to those in the reference group whose weight remained stable [16].

3.4. Are all dairy products equivalent in terms of their benefits for bone health?

Recommended daily calcium intakes (Table 2) can be achieved by ingesting 3 dairy products a day (which provide approximately

Recommendation [B – scientific assumption]

In overweight and obese patients, weight loss is recommended on account of the beneficial effect on a number of clinical and biological parameters. For this population, we recommend regular, suitably adapted, weight-bearing physical activity, combined with sufficient levels of vitamin D and calcium intake, to limit the bone loss induced by restricted calorie intake. On the other hand, for normal-weight individuals, weight-loss diets are advised against owing to their adverse effects on bone mass, and possibly fracture risk.

Table 2
Calcium and proteins intakes recommended by the French Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement, et du travail (ANSES) [17,18].

Calcium	- Average nutritional requirement: 750 mg/day - Satisfactory intake: 950 mg/day - Upper safety limit: 2500 mg/day
Proteins	- Nutritional reference for the population: 0.83 g/kg/day, 10–20% of total energy intake for adults <60 years; elderly: 1 g/kg/day - Upper safety limit: 2.2 g/kg/day (27% of total energy intake)

150 to 200 mg of calcium per portion) [17,18]. Dairy products are high in calcium and have good bioavailability compared to other sources of calcium, such as plant-based sources [19,20]. Dairy products are also a source of protein, other nutrients that contribute to good bone health (e.g., phosphorus and vitamins) and, in the case of fermented dairy products, probiotics.

In a recent meta-analysis of randomised control trials, dairy consumption was found to have a beneficial effect on BMD at all sites (lumbar spine: standardised mean difference (SMD) = 0.21 g/cm^2, CI95% = 0.05–0.37, P = 0.009; femoral neck: SMD = 0.36 g/cm^2, CI95% = 0.19–0.53, P < 0.001; total hip: SMD = 0.37 g/cm^2, CI95% = 0.20–0.55, P < 0.001) [21]. In a prospective, randomised intervention study conducted in retirement homes, a 33% reduction in the incidence of fractures, a 46% reduction in hip fractures and an 11% reduction in falls was found in homes in which the number of dairy products in residents' diets was increased from 2 to 3.5 a day on average, compared to homes in which residents' diets remained unchanged [22].

Regardless of the type of dairy product, all of the meta-analyses with fracture-risk data reported either beneficial associations or no association with fracture risk, and possibly stronger associations in the case of fermented dairy products (Table 3) [23–28]. No studies investigating the effects of sheep- or goat-milk dairy products on BMD or fracture risk were found in the literature.

Recommendation [B – scientific assumption]

The literature shows that the consumption of dairy products has a beneficial effect on BMD at all sites, and beneficial or neutral associations with fracture risk. The beneficial effect on fracture risk seems to be more pronounced with fermented dairy products (yoghurt, cheese). In patients with osteoporosis or in the prevention of osteoporosis, we recommend the consumption of 2 to 3 different dairy products a day.

3.5. Does excessive intake of dietary calcium and dairy products pose a health risk?

Contrary to conventional wisdom, which holds that dairy products' high saturated fatty acid content could adversely affect the lipid profile and increase the risk of cardiovascular diseases, the consumption of dairy products – except butter, which is a fatty substance – is associated with a favourable lipid profile and a reduction in the risk of cardiovascular disease and type-2 diabetes [29–31]. The "matrix" effect of dairy products – i.e., the interaction between the various nutrients they contain – affects their physiological effects. As such, the adverse effect of dairy products on the lipid profile is less pronounced with the consumption of cheese than with other high-fat dairy products, such as butter or cream [32]. Increasing the intake of dairy products in general is not associated with a worsening of the lipid profile (triglycerides, total cholesterol, and LDL and HDL cholesterol), or even with an improvement in the lipid profile in the case of low-fat dairy products [33].

Furthermore, the dietary intake of calcium in the same recommended amounts is associated with either no increase in cardiovascular risk [34], or a reduction in cardiovascular risk [35], especially with fermented dairy products [36]. However, cheese should be consumed only in moderate amounts because of its high energy density – due to its lipid content – and the amount of salt it contains.

Patients with a history of urinary lithiasis often restrict their calcium intake. Yet low calcium intake is detrimental in that it promotes the onset of oxalate lithiasis by increasing the digestive absorption of oxalates in response to the reduction in calcium-oxalate complexes in the intestine [37]. No heightened risk of lithiasis has been reported with recommended calcium intake levels by age, i.e., between 800 and 1200 mg/day [38].

Recommendation [B – scientific assumption]

Dietary calcium intake should be evaluated before prescribing supplementation. Neither a heightened cardiovascular or lithiasis risk, nor a negative association with the lipid profile, has been found with recommended levels of dietary calcium intake (approximately 1g/day). The consumption of dairy products can be encouraged as this is associated with favourable lipid profiles and a reduction in cardiovascular risk.

3.6. Is the calcium from plant-based beverages and mineral waters as beneficial for bone health as the calcium from dairy products?

Some mineral waters are a good dietary source of calcium as the bioavailability of the calcium in them is equivalent to the bioavailability of calcium in dairy products [39]. Calcium-rich mineral waters may contribute to maintaining BMD and reducing hip fracture risk, as reported in the only available observational study [40,41]. When waters with the same calcium content were compared, bicarbonate-rich waters were found to reduce bone remodelling more than sulphate-rich waters. However, for some of bicarbonate-rich waters, the possible intake of salt should also be considered as salt induces calciuria [42].

Plant-based beverages should be enriched to levels approaching the calcium content of milk. Moreover, with the exception of soy-based beverages, plant-based beverages contain very little protein [43]. To the best of our knowledge, no BMD or fracture data are available in connection with the consumption of plant-based beverages, other than an intervention study, which found that cow's milk had a more favourable effect on the prevention of post-menopausal

Table 3
Fracture risk according to consumption of dairy products (higher vs. highest) in recent meta-analyses (According to [18]).

		Milk		Yoghurt		Cheese		Any dairy product	
		Number of studies	Risk (CI95%)	Number of studies	Risk (CI95%)	Number of studies	Risk (CI95%)	Number of studies	Risk (CI95%)
Bian et al. (2018) [23]	Hip fracture	10	RR = 0.91 (0.74, 1.12)	3	RR = 0.75 (0.66, 0.86)[a]	3	RR = 0.68 (0.61, 0.77)[a]	2	RR = 1.02 (0.93, 1.12)
	Hip fracture	7	OR = 0.71 (0.55, 0.91)[a]	1	OR = 0.77 (0.39, 1.52)	3	OR = 0.77 (0.53, 1.11)	1	OR = 1.70 (0.52, 5.59)
Matia-Martin et al. (2019) [24]	All fractures	3	HR = 1.05 (0.94, 1.18)	2	HR = 0.92 (0.87, 0.98)	2	HR = 0.89 (0.81, 0.98)		
	Hip fracture	5	HR = 0.91 (0.69, 1.21)	5	HR = 0.87 (0.71, 1.05)	4	HR = 0.80 (0.62, 1.03)		
	Vertebral fracture	3	HR = 0.81 (0.66, 1.00)	1	HR = 1.18 (0.59, 2.39)	1	HR = 0.65 (0.33, 1.27)		
Malmir et al. (2020) [25]	Hip fracture	10	RR = 0.93 (0.75, 1.15)		-		-	6	RR = 0.90 (0.73, 1.11)
	Hip fracture	9	OR = 0.75 (0.57, 0.99)[a]		-		-	3	OR = 0.86 (0.53, 1.38)
Hidayat et al. (2020) [26]	Hip fracture	9	RR = 0.86 (0.73, 1.02)	4	RR = 0.78 (0.68, 0.90)[a]	4	RR = 0.85 (0.66, 1.08)		-
Ong et al. (2020) [27]	Hip fracture		-	3	RR = 0.76 (0.63, 0.80)[a]	2	RR = 0.89 (0.73, 1.10)		-

RR: Relative Risk (cohort studies); HR: Hazard Ratio (cohort studies); OR; Odds Ratio (case-control studies).
[a] Statistically significant.

bone loss than a soy-based drink [44]. Additionally, dairy products provide a wide range of nutrients that are beneficial to bone health, including proteins, which are found only in small quantities or not at all in plant-based drinks and mineral waters.

Recommendation [C – low level of evidence]
Mineral waters are a source of dietary calcium, whose bioavailability is equivalent to that of calcium in dairy products. Calcium- and bicarbonate-rich waters that are poor in sulphates should be preferred. In patients with osteoporosis or in the prevention of osteoporosis, we recommend the consumption of calcium-rich mineral waters (>250–300 mg Ca/L) if the daily consumption of dairy products is not enough to attain optimal calcium intake levels. There is no data suggesting that plant-based beverages are equivalent to animal milks as a source of calcium. As such, there are no arguments in favour of recommending their consumption for bone health.

3.7. *Does protein intake (quality and quantity) affect bone health?*

Approximately one-third of bone mass is composed of proteins. Proteins form the structure of the organic matrix of bone (collagen) and contribute to bone-tissue function (non-collagen proteins).

During bone remodelling, the amino acids released as a result of proteolysis cannot be reused *in situ*. Furthermore, some amino acids – the essential amino acids – can only be obtained through diet. In addition to their structural role, dietary proteins stimulate the release of IGF1 (*Insulin-like growth factor 1*), a hormone that has an anabolic effect on musculoskeletal tissue [45]. Optimal protein intake is therefore essential for acquiring and maintaining bone mass. A distinction should also be made between animal protein and plant protein. To attain recommended daily protein intake levels (Table 2), diets should include "high-quality" proteins – i.e., proteins that are easily digested, rich in essential amino acids, and available for protein synthesis – the sources of which are primarily animal (meat, fish, dairy products and eggs), but also include soybean.

Two (2) meta-analyses reported a protective effect of protein on lumbar spine BMD [46,47]. On the other hand, no effect was found at the hip. Where fracture data is concerned, the literature is limited to cohort observational studies [48]. In elderly individuals with osteoporosis, optimal protein intake levels are associated with an 11-16% reduction in hip fracture risk (Table 4) [46,49–52]. However, the beneficial effect of protein intake on bone health is only observed if calcium and vitamin D intake levels are optimal (1 g/day and 800 IU/day, respectively) as part of a balanced diet with suitable calorie intake levels [53,54].

In menopausal women, individuals with osteoporosis and the elderly, the recommended daily protein intake is at least 1–1.2 g/kg/day, with at least 20 to 30 g of "high quality" protein per meal (Table 5**)**. In the most fragile elderly individuals, or in those with a chronic illness, because of anabolic resistance to dietary protein and splanchnic sequestration, increasing these intake levels to 1–1.5 g/kg/day is recommended (in the absence of severe renal impairment) [55].

It is generally accepted that "high quality" dietary proteins induce a better anabolic response since they are rich in essential amino acids, and particularly leucine. However, in the meta-analyses investigating associations between protein intake and BMD or fracture risk, no significant differences were found between animal and plant proteins [46,52,56]. Nonetheless, partially replacing animal protein with plant protein may be associated with an increase in bone remodelling markers and parathyroid hormone [57]. Some cohort studies suggest more favourable associations between calculated bone strength and animal protein intake compared to plant protein intake [58,59]. Apart from being a source of calcium, dairy products, especially whey, which is rich in leucine, are a source of "high quality" protein [28].

Recommendation [B – scientific assumption]
In patients with osteoporosis or in the prevention of osteoporosis, we recommend a protein intake of at least 1-1.2 g/kg/day as part of a balanced diet with suitably adapted calorie, calcium and vitamin D intakes. Protein intakes should include "high quality" animal proteins. Dairy products that are rich in "high quality" protein and calcium are recommended.

Table 4
Meta-analyses comparing fracture risk between highest versus lowest level of protein consumption.

Meta-analysis	Population	Fracture site	Total protein		Animal protein		Plant-based protein	
			Number of studies	Risk (CI95%)	Number of studies	Risk (CI95%)	Number of studies	Risk (CI95%)
Darling, 2009 [46]	Adults ≥ 18 years	Hip fractures	3	RR = 0.75 (0.47, 1.21)	3	RR = 0.83 (0.54, 1.30)	2	RR = 1.21 (0.82, 1.79)
Wu, 2015 [49]	Adults ≥ 18 years	All fractures	3	RR = 0.99 (0.97, 1.02)	2	RR = 0.79 (0.32, 1.96)		
		Hip fractures	6	RR = 0.89 (0.82, 0.97)[a]	4	RR = 1.04 (0.70, 1.54)		
Wallace, 2017 [50]	Adults ≥ 18 years	Hip fractures	5	RR = 0.84 (0.73, 0.95)[a]				
Groenendijk, 2019 [51]	Adults > 65 years	Hip fractures			4	HR = 0.89 (0.84, 0.94)[a]		
Darling, 2019 [52]	Adults ≥ 18 years	All fractures	4 3 3	RR = 0.94 (0.72, 1.23) HR = 0.82 (0.59, 1.14); 0.79[b] (0.64, 0.97)[a] OR = 0.69 (0.30, 1.68)	4	RR = 0.98 (0.76, 1.27)	3	RR = 0.97 (0.89, 1.09)

RR: Relative Risk (cohort studies); HR: Hazard Ratio (cohort studies); OR; Odds Ratio (case-control studies).
[a] Statistically significant.
[b] If removal the study with low calcium intake.

Table 5
Mean calcium and protein content by food.

Class of food	Food	Calcium		Protein	
		Content per 100 g	Portion equivalent to 300 mg of calcium[a]	Content per 100 g	Portion (g) equivalent to 20 g of protein
Meat, fish and eggs, or equivalent	Cooked meat (average quality)	10.4 mg	2.9 kg	27.2 g	75 g
	Chicken fillet	6.3 mg	4.8 kg	20.7 g	100 g
	Cooked fish	29.9 mg	1 kg	23.5 g	85 g
	Hard-boiled eggs	41 mg	732 (14 eggs)	13.5 g	150 g (3 eggs)
	Plain tofu	100 mg	300 g	14.7 g	140 g
Dairy products	Cheese	626 mg	48 g (1 portion)	21.3 g	90 g (2 portions)
	Fromage blanc	122 mg	246 g (2 small containers)	7 g	300 g (3 small containers)
	Yoghurt	121 mg	248 g (2 yoghurts)	3.6 g	500 g (4 yoghurts)
	Milk	117 mg	0.25 litres	3.3 g	0.5 litres
Nuts, cereals and legumes	Walnuts	75 mg	400 g	15.7 g	130 g
	Almonds (with skin)	260 mg	115 g	22.6vg	90 g
	Soybean	220 mg	136 g	37.8 g	50 g
	White rice (cooked)	14 mg	2.1 kg	3.1 g	650 g
	Pasta (cooked)	17 mg	1.8 kg	4.4 g	450 g
	Whole-wheat pasta (cooked)	22 mg	1.4 kg	4.9 g	410 g
	Lentils (cooked)	40 mg	750 g	10.1 g	200 g
	Chickpeas (cooked)	72 mg	417 g	8.3 g	240 g
	Bread	31 mg	968 g (4 baguettes)	9.0 g	220 g (1 baguette)
	Soy drink, plain, not enriched with calcium	12 mg	2500 g (approx. 2.5 litres)	3.6 g	555 g (approx. 0.5 litres)
	Soy drink, plain, calcium-enriched	98 mg	306 g (approx. 0.3 litres)	3.7 g	540 g (approx. 0.5 litres)
	Oat milk, plain	1 mg	Not applicable	< 0.5 g	> 4 litres
Fruit and vegetables	Green beans (cooked)	55 mg	545 g	2 g	1 kg
	Green peas (cooked)	33 mg	909 g	5.8 g	340 g
	Spinach (cooked)	140 mg	214 g	3.2 g	625 g
	Quinoa (cooked)	23 mg	1.3 kg	5 g	400 g
	Apple (raw)	5 mg	6 kg	0.3 g	6.6 kg
	Orange	66 mg	0.5 kg	0.8 g	2.5 kg
Other	Spirulina	120 mg	250 g	57.5 g	35 g

[a] At equal calcium intakes, calcium absorption varies depending on bioavailability. Source: Ciqual food composition Table 2020 (ANSES) http://ciqual.anses.fr/

3.8. Are high-protein, high-calorie oral nutritional supplements good for bone health?

The prevalence of undernutrition is high in the elderly, especially after hip fractures. It is estimated that between 18.7 and 45.7% of older people are undernourished [60]. Undernutrition in older people is associated with an increase in overall fragility, sarcopenia and falls [55].

Currently, data on the efficacy of high-protein, high-calorie oral nutritional supplements (ONSs) on bone health are lacking. After a hip fracture, ONSs could help prevent postoperative complications, improve functional recovery, reduce length of stay and, possibly,

reduce mortality. However, the methodological quality of the available trials is poor [60–62].

Recommendation [C – low level of evidence]
In patients with osteoporosis, protein intake should be adapted in line with nutritional status (dietary advice; increase in dietary intake and/or ONSs, such as high-protein drinks). The use of ONSs should not be systematic: they should be reserved for undernourished patients only, or when it is difficult to change the patient's diet. In patients with osteoporosis who are not undernourished, we do not recommend the systematic use of high-protein, high-calorie ONSs on account of the lack of scientific data demonstrating a beneficial effect on bone health.

3.9. Do acid-producing diets adversely affect bone health?

The "dietary acid load hypothesis as the cause of osteoporosis" emerged in the 1960s. According to this hypothesis, animal protein, and to a lesser extent cereals – both endogenous sources of acids (sulphur-containing amino acids and phosphoproteins) – caused metabolic acidosis and a reduction in urinary pH, leading to excessive bone resorption as a compensatory response inducing the release of cations (calcium, calcium bicarbonate) from bone, thereby disrupting bone and calcium homeostasis, and ultimately leading to hypercalciuria. The acid-producing potential of a food item is calculated using indices such as the PRAL (*potential renal net acid load*) index or the NEAP (*net endogenous acid production*) index.

This hypothesis has since been invalidated as, in the absence of renal impairment and calcium and vitamin D deficiencies:

- diet, whether acid or alkaline, does not modify systemic pH [63];
- no association has been found between endogenous acid production and BMD, fracture risk or osteoporosis [64–66];
- high protein intake does not affect the calcium balance. Dietary protein-induced hypercalciuria is due to an increase in concomitant calcium intake and the intestinal absorption of calcium (mediated by IGF-1), and not the release of calcium from bone [45].

Recommendation [B – scientific assumption]
In the absence of chronic renal impairment and calcium and vitamin D deficiency, there is no scientific evidence to suggest that acid-producing diets have an adverse effect on bone health.

3.10. Are vitamin D-enriched foods an alternative to supplementation as a means of optimising vitamin D status?

Vitamin D synthesis in the skin depends on exposure to sunlight and accounts for at least 70% of vitamin D status (serum 25-OH-D values). It is however limited by a number of environmental factors (climate, latitude, pollution, etc.) and cultural factors (lifestyle, clothing, sunscreens, etc.). Furthermore, dietary vitamin D intake is generally very moderate (mainly through oil-rich fish and cod liver oil). Food enrichment is the process of adding bioactive compounds to food to prevent/treat nutrient deficiencies. Several clinical trials investigating the efficacy of vitamin D-enriched foods *versus* placebo have been conducted in adults and have reported an increase in serum 25-OH-D values [67].

In the only meta-analysis that has been conducted – covering 6 intervention studies –, the consumption of vitamin D-enriched foods was found to have a moderate beneficial effect on BMD compared to placebo [68]. The literature on the effect of vitamin D-enriched foods on fracture risk is scarce, and all the more so as most of the studies considered medically prescribed supplementation at the same time. A study covering the French population, based on a simulation model including three age groups – 60–69 years, 70–79 years and 80–89 years – suggested that the regular consumption of vitamin D-enriched dairy products could significantly reduce the number of fractures – especially at the hip – and could be an inexpensive strategy, especially for persons aged over 70 years [69].

Very few studies have compared the efficacy of medically prescribed supplementation versus enriched foods in optimising vitamin D status. Although, theoretically, vitamin D-enriched foods could be an alternative to supplementation, evidence of a beneficial effect of vitamin D on bone health has only been demonstrated with supplementation.

Recommendation [C – low level of evidence]
In cases of vitamin D deficiency, vitamin D-enriched foods could be an alternative to supplementation as a means of optimising vitamin D status, but there is not enough scientific evidence to assert that they are comparable to medically prescribed supplementation in terms of their effect on bone health.

3.11. To what extent do other vitamins affect bone health?

The relationship between vitamin intake and bone health can be considered from different angles, e.g., by referring to preclinical studies on the known effects of specific vitamins on bone cells or calcium and phosphorus metabolism, studies on the prevalence of vitamin deficiencies and high-risk situations, epidemiological studies investigating dietary intake or circulating levels of specific vitamins, and intervention studies investigating the effect of increasing vitamin intake (in most cases using supplements) (Table 6) [18].

The vitamins whose effect on bone metabolism and calcium and phosphorus metabolism has been clearly established are vitamins D and K. In the absence of undernutrition or chronic diseases of the digestive tract, vitamin insufficiencies/deficiencies in adults mainly concern vitamins D, B9 (folates) and B12. Deficiencies in vitamins A, B1, B2, B3, B5, B6, B8, C, E and K are very rare. Deficiencies in vitamin B12 – sourced from animal-derived foods only – are most notably observed in vegans and individuals who have undergone bariatric surgery. Vitamin A, B6, C, D and E supplementation in excess of recommended doses is not without health risks [18].

Favourable associations have been reported between bone health and an increase in dietary intake of vitamins D, K, B9 (folates), B6 (if intake is not too high), C and E. Where vitamin A is concerned, the data are conflicting, with provitamin carotenoids showing a probable beneficial effect, and retinol an adverse effect. High intake levels of vitamins B6 and B12 have been reported to be associated with an increase in risk fracture.

In studies investigating bone health in connection with circulating vitamin levels, insufficiencies/deficiencies in vitamin D, K and B9 (folates) were associated with lower BMD and even an increase in fracture risk.

Table 6
Vitamins and bone health (adapted from reference [18]).

Vitamins	Demonstrated effect on bone and calcium and phosphorus metabolism	Insufficiency/deficiency in adults	Potential health risks when recommended doses exceeded	Associations between increase in dietary vitamin intake and bone health	Associations between circulating vitamin levels and bone health	Beneficial effects of supplementation on bone health in intervention study
D	(Calcium and phosphorus metabolism, bone remodelling)	Frequent	(hypercalcemia)	Favourable	Insufficiency/deficiency is deleterious	Demonstrated for insufficiency/deficiency
K	(activation of osteocalcin)	Very rare	Not demonstrated	Favourable	Insufficiency/deficiency is deleterious	No demonstrated beneficial effect on fracture risk. Beneficial effect on BMD with vitamin K2 only
A	± (increase in bone formation and reduction in bone resorption; inhibits mineralisation)	Very rare	(hepatotoxic and teratogenic effects; increase in mortality)	Favourable for provitamin carotenoids; deleterious for retinol	Deleterious with retinol; favourable with provitamin carotenoids.	Not enough data to draw conclusions (1 study with retinol reporting no effect on BRMs)
B6 (pyridoxine)	Not demonstrated. Substrate for alkaline phosphatase	Very rare	(reversible peripheral neuropathies)	Favourable without the need for high intakes; unfavourable with high intakes	Uncertain	- B6 supplementation has no effect on fracture risk, but high doses associated with increase in hip fracture risk. - Folate-B12 supplementation has no effect on fracture risk, except in individuals > 80 years, but increase in cases of cancer; reduces homocysteine but no effect on BRMs. - B6-folates-B12 supplementation: no effect on fracture risk
B9 (folic acid or folate)	± (increase in bone resorption and decrease in bone formation; in the case of hyperhomocysteinemia, alteration of bone matrix induced by folate and B12 deficiency)	Possible	Not demonstrated	Favourable	Insufficiency/deficiency is deleterious	
B12 (cobalamin or cyanocobalamin).		Possible (vegans)	Not demonstrated	Deleterious with high intake	No association	
B1 (thiamine)	±	Very rare	Not demonstrated	No data	No data	No studies
B2 (riboflavin)	Not demonstrated	Very rare	Not demonstrated	No data	No data	No studies
B3 (niacin)	Not demonstrated	Very rare	Not demonstrated	No data	No data	No studies
B5 (pantothenic acid)	±	Very rare	Not demonstrated	No data	No data	No studies
B8 (biotin)	Not demonstrated	Very rare	Not demonstrated	No data	No data	No studies
C (ascorbic acid)	± (antioxidant properties)	Very rare	(pro-oxidant effect with high-dose vitamin C and iron supplementation; increase in mortality)	Favourable	Conflicting data	No studies
E	± (due to anti-inflammatory and immumodulatory effects)	Very rare	(increase in mortality)	Favourable	No data	Not enough data to draw conclusions (1 study reporting a favourable effect on BRMs)

BRMs: bone remodelling markers

The findings in the 2 types of studies mentioned above are difficult to interpret in terms of causality as many confounding factors related to dietary habits, lifestyle and even genetic background can affect bone parameters and fracture risk.

Intervention studies – which offer the highest level of evidence – were very rare and often suffered from many potential biases. They were often of low statistical power, in some cases testing combinations of vitamin supplements, and control groups were not adequate for detecting the effect of a specific vitamin. The reported beneficial associations between fracture risk and dietary intake or plasma concentration of vitamin K were not confirmed in meta-analyses of the intervention studies, which suggest a beneficial effect of vitamin K (menaquinone) on BMD only [70–76].

Recommendation [C – low level of evidence]
Except in the case of vitamin D, there is not enough scientific evidence to recommend supplementation with other vitamins to improve bone health.

3.12. What effects does soda, tea and coffee consumption have on bone health?

Studies investigating the effect of sodas on bone health are scarce and also consider other non-alcoholic drinks, such as tea and coffee. A recent meta-analysis suggests that an association exists between lower BMD and high sodas consumption in young, healthy adults [77]. However, the findings reported in that meta-analysis are difficult to extrapolate to clinical practice since most of the bone mineral density analyses were performed for the entire body and, in most cases, the subjects were young, healthy adults. In that meta-analysis, three cohort studies found that fracture risk started to increase with the consumption of 1 to 2 sodas a day. Moreover, high soda consumption was voluntarily associated with insufficient intake of dairy products, or other dietary or lifestyle practices that are less beneficial to bone health.

The association between tea consumption and bone health has been the subject of investigation since the 1990s, with conflicting results. However, in the most recent studies, higher hip and lumbar spine BMDs have been reported in tea drinkers compared to non-tea drinkers [78]. This may be due to the effects of the polyphenolic compounds (catechins) in tea. In most of the publications, tea consumption is also associated with a reduction in fracture risk [79].

Due to the negative effect of caffeine on calcium metabolism – i.e., an increase in the excretion and a reduction in the absorption of calcium – many studies have attempted to investigate the effect of coffee on bone metabolism. They suggest a moderate negative association between high coffee consumption (>400 mg/day of caffeine, or approximately 3 cups of coffee) and BMD, compared to low coffee consumption [80]. Regarding coffee consumption and fracture risk, a meta-analysis reported an association between coffee consumption and an increase in fracture risk in women (RR (CI95%) = 1.14 (1.05–1.24)), and a reduction in fracture risk in men (RR = 0.76 (0.62–0.94)) [81]. Another recent meta-analysis suggested an association between lower incidence of hip fractures and moderate coffee consumption (up to 3 cups a day) compared to low coffee consumption (RR(CI95%) = 0.86 (0.67–1.05)), regardless of sex. However, the association disappeared after adjusting for potential confounding factors, such as calorie and calcium intake, and tea consumption [82].

Recommendation [B – scientific assumption]
Daily soda consumption seems to have a negative effect on bone health. As such, it is recommended to restrict soda consumption, especially since this is often associated with a reduction in the intake of dairy products. High tea consumption seems to have a beneficial effect on bone health. However, the benefits are not well enough established to recommend increasing tea consumption. The consumption of up to 3 cups of coffee a day seems to have no adverse effects on bone health.

3.13. Does alcohol consumption adversely affect bone health?

Several studies have investigated the association between alcohol consumption (drinking) and bone health. The results are variable, reflecting the complexity of the association, which depends on age, sex, menopause status, mode of consumption – regular or acute (binge drinking), type of alcohol, and other confounding factors associated with drinking (smoking, comorbidities, etc.), whether excessive or not [83,84]. An additional difficulty lies in the lack of consensus on what constitutes light, moderate and heavy drinking. Gaddini et al; propose the following definitions: light (occasional consumption of small amounts); moderate (regular consumption – i.e., $\geq$ 3 days a week, with $\leq$ 1 glass a day for women, and $\leq$ 2 glasses a day for men); and heavy (consumption exceeding the thresholds defined for moderate consumption, either regularly (most days of the week) or occasionally ($\geq$ 5 glasses, i.e. binge drinking) [85].

Moderate drinking is more often associated with higher BMD values and lower hip fracture risk than light drinking. This has been demonstrated especially in menopausal women who drink small amounts of red wine [86]. This finding in menopausal women could be due to the protective effect of the polyphenols and terpenes (resveratrol) in wine. On the other hand, heavy drinking is associated with lower BMD values and higher hip fracture risk [85,87]. Furthermore, regardless of its effects on bone health, drinking increases the risk of falls and, consequently, fractures.

Recommendation [B – scientific assumption]
Light to moderate alcohol consumption seems to have no adverse effect on bone health in women. On the other hand, heavy consumption is associated with lower BMD values and higher fracture risk. However, since alcohol is addictive and detrimental to health in general, alcohol consumption, even in moderation, is not recommended.

3.14. What are the expected benefits of phytoestrogens for bone health?

Phytoestrogens are plant-based compounds that are similar in structure to estradiol. Families of molecules that are classified as phytoestrogens include lignans, isoflavones and some flavonoids. Dietary sources of lignans include flaxseed and whole-grain cereals. Soybean is a major source of isoflavones. A distinction should be made between:

- studies on dietary soy intake, and;
- intervention studies on soy-based dietary supplements.

In Asian menopausal women, high dietary soy intake is associated with higher BMD values [88]. It is worth noting that soy is also a source of “high-quality” protein. However, it is difficult to

Table 7
Questions on diet and dietary recommendations in the prevention and treatment of osteoporosis.

Question	Recommendation	HAS grade [1]	Level of agreement of working group[a]
1 - What are the expected benefits of the Mediterranean diet for bone health?	A Mediterranean-type diet is associated with better bone health. It is therefore recommended for patients with osteoporosis, or in the prevention of osteoporosis.	B – scientific assumption	9.3 (1.1)
2 - Are vegetarian and vegan diets harmful to bone health?	Vegan diets, and to a lesser extent, vegetarian diets, are associated with poorer bone health. Vegan diets should therefore be avoided in patients with osteoporosis, or in the prevention of osteoporosis. In vegans, an adjustment of calcium intake should be systematically proposed.	B – scientific assumption	9.5 (1.0)
3 - How do voluntary weight-loss diets affect bone health?	In overweight and obese patients, weight loss is recommended on account of the beneficial effect on a number of clinical and biological parameters. For this population, we recommend regular, suitably adapted, weight-bearing physical activity, combined with sufficient levels of vitamin D and calcium intake, to limit the bone loss induced by restricted calorie intake. On the other hand, for normal-weight individuals, weight-loss diets are advised against owing to their adverse effects on bone mass, and possibly fracture risk.	B – scientific assumption	9.5 (0.9)
4 - Are all dairy products equivalent in terms of their benefits for bone health?	The literature shows that the consumption of dairy products has a beneficial effect on BMD at all sites, and beneficial or neutral associations with fracture risk. The beneficial effect on fracture risk seems to be more pronounced with fermented dairy products (yoghurt, cheese). In patients with osteoporosis or in the prevention of osteoporosis, we recommend the consumption of 2 to 3 different dairy products a day.	B – scientific assumption	9.5 (1.0)
5 - Does excessive intake of dietary calcium and dairy products pose a health risk?	Dietary calcium intake should be evaluated before prescribing supplementation. Neither a heightened cardiovascular or lithiasis risk, nor a negative association with the lipid profile, has been found with recommended levels of dietary calcium intake (approximately 1g/day). The consumption of dairy products can be encouraged as this is associated with favourable lipid profiles and a reduction in cardiovascular risk.	B – scientific assumption	9.3 (1.0)
6 - Is the calcium from plant-based beverages and mineral waters as beneficial for bone health as the calcium from dairy products?	Mineral waters are a source of dietary calcium, whose bioavailability is equivalent to that of calcium in dairy products. Calcium- and bicarbonate-rich waters that are poor in sulphates should be preferred. In patients with osteoporosis or in the prevention of osteoporosis, we recommend the consumption of calcium-rich mineral waters (>250–300 mg Ca/L) if the daily consumption of dairy products is not enough to attain optimal calcium intake levels. There is no data suggesting that plant-based beverages are equivalent to animal milks as a source of calcium. As such, there are no arguments in favour of recommending their consumption for bone health.	C – low level of evidence	9.1 (1.2)
7 - Does protein intake (quality and quantity) affect bone health?	In patients with osteoporosis or in the prevention of osteoporosis, we recommend a protein intake of at least 1–1.2 g/kg/day as part of a balanced diet with suitably adapted calorie, calcium and vitamin D intakes. Protein intakes should include “high quality” animal proteins. Dairy products that are rich in “high quality” protein and calcium are recommended.	B – scientific assumption	9.2 (1.3)
8 - Are high-protein, high-calorie oral nutritional supplements good for bone health?	In patients with osteoporosis, protein intake should be adapted in line with nutritional status (dietary advice; increase in dietary intake and/or ONSs, such as high-protein drinks). The use of ONSs should not be systematic: they should be reserved for undernourished patients only, or when it is difficult to change the patient’s diet. In patients with osteoporosis who are not undernourished, we do not recommend the systematic use of high-protein, high-calorie ONSs on account of the lack of scientific data demonstrating a beneficial effect on bone health.	C – low level of evidence	9.3 (1.1)
9 - Do acid-producing diets adversely affect bone health?	In the absence of chronic renal impairment and calcium and vitamin D deficiency, there is no scientific evidence to suggest that acid-producing diets have an adverse effect on bone health.	B – scientific assumption	9.4 (1.1)
10 - Are vitamin D-enriched foods an alternative to supplementation as a means of optimising vitamin D status?	In cases of vitamin D insufficiency, vitamin D-enriched foods could be an alternative to supplementation as a means of optimising vitamin D status, but there is not enough scientific evidence to assert that they are comparable to medically prescribed supplementation in terms of their effect on bone health.	C – low level of evidence	9.2 (1.5)
11 - To what extent do other vitamins affect bone health?	Except in the case of vitamin D, there is not enough scientific evidence to recommend supplementation with other vitamins to improve bone health.	C – low level of evidence	9.5 (0.7)

Table 7 (*Continued*)

Question	Recommendation	HAS grade [1]	Level of agreement of working group[a]
12 - What effects does soda, tea and coffee consumption have on bone health?	Daily soda consumption seems to have a negative effect on bone health. As such, it is recommended to restrict soda consumption, especially since this is often associated with a reduction in the intake of dairy products. High tea consumption seems to have a beneficial effect on bone health. However, the benefits are not well enough established to recommend increasing tea consumption. The consumption of up to 3 cups of coffee a day seems to have no adverse effects on bone health.	B – scientific assumption	9.3 (1.1)
13 - Does alcohol consumption adversely affect bone health?	Light to moderate alcohol consumption seems to have no adverse effect on bone health in women. On the other hand, heavy consumption is associated with lower BMD values and higher fracture risk. However, since alcohol is addictive and detrimental to health in general, alcohol consumption, even at moderate levels, is not recommended.	B – scientific assumption	9.4 (0.9)
14 - What are the expected benefits of phytoestrogens for bone health?	Phytoestrogens seem to have a beneficial effect on bone health in Asian women, in dietary conditions consistent with practices in those populations. As far as Western women are concerned, there is not enough data in the literature to recommend a soy-based diet or soy-based dietary supplements in patients with osteoporosis or in the prevention of osteoporosis.	B – scientific assumption	9.6 (0.8)
15 - What are the expected benefits of pre- and probiotics for bone health?	Prebiotics, which form the substrate for our bacterial microflora, have a modest beneficial effect on intestinal calcium absorption. Although some probiotic strains have been reported to be associated with a modest reduction in bone loss, target populations, optimal bacterial strains and conditions of intake are not sufficiently well defined to specifically recommend their use in patients with osteoporosis or in the prevention of osteoporosis.	B – scientific assumption	9.5 (0.8)

[a] Agreement score between 0 and 10 where 10 is complete agreement.

extrapolate this finding to Western populations due to differences in exposure and genetic background. A beneficial effect of isoflavone-rich dietary supplements (genistein and daidzein) has been demonstrated in menopausal women in some of the intervention studies that have been published to date. In 2 recently published meta-analyses (2017 and 2020) of randomised controlled trials in premenopausal and menopausal women, improvements in BMD were reported at the lumbar spine and femoral neck [89,90], but this was not found in the meta-analysis published in 2010 by Ricci et al. [91].

Fracture risk has been investigated mainly in Asian populations. High dietary intakes of tofu, soy protein and isoflavone equivalents are associated with a 21 to 36% reduction in hip fracture risk in women, but not in men [92].

Recommendation [B – scientific assumption]

Phytoestrogens seem to have a beneficial effect on bone health in Asian women, in dietary conditions consistent with practices in those populations. As far as Western women are concerned, there is not enough data in the literature to recommend a soy-based diet or soy-based dietary supplements in patients with osteoporosis or in the prevention of osteoporosis.

3.15. What are the expected benefits of pre- and probiotics for bone health?

Prebiotics are short-chain carbohydrates (oligosaccharides) that cannot be digested by human digestive enzymes, but which selectively improve the activity of specific groups of beneficial bacteria in the colon. The fermentation of prebiotics as a result of the activity of these bacteria leads to the production of short-chain fatty acids and various metabolites (postbiotics). Probiotics are living microorganisms which, in controlled quantities, are beneficial to their hosts. A systematic literature review of control studies on the effects of pre- and probiotics has recently been published [93]. Owing to the diversity of pre- and probiotics, the literature is scarce. It is highly probable that the microbiota plays a role in bone health.

As far as prebiotics are concerned, several studies, investigating mainly calcium absorption, have been conducted in children and adolescents, but only a few have been conducted in adults. No studies investigating the role of prebiotics on fracture risk have been published. In summary, prebiotics have only modest, short-term effects on calcium absorption. In the 3 studies investigating the effect of prebiotics on BMD, the results were negative [93].

Of the 5 controlled studies investigating the effect of probiotics on bone loss, 4 reported a significant reduction in bone loss. The magnitude of the beneficial effect on BMD is comparable to that observed with vitamin D and calcium supplements [93].

Recommendation [B – scientific assumption]

Prebiotics, which form the substrate for our bacterial microflora, have a modest beneficial effect on intestinal calcium absorption. Although some probiotic strains have been reported to be associated with a modest reduction in bone loss, target populations, optimal bacterial strains and conditions of intake are not sufficiently well defined to recommend their specific use in patients with osteoporosis or in the prevention of osteoporosis.

4. Discussion

Nutritional care is an integral part of osteoporosis prevention and treatment. These recommendations are based on 15 questions in connection with daily practices (Table 7) that address, in very pragmatic terms, various aspects of nutritional care in patients seen

for osteoporosis, as well as topics other than calcium and vitamin D supplementation. To the best of our knowledge, they are the first set of recommendations of this type, addressing globally the effect of diet on bone health. Producing these recommendations also provided an opportunity to dispel certain misconceptions about the role of diet in bone health by referring to scientific data. An example of this is the supposedly negative effect of acid-producing diets on bone health (recommendation 9). On the contrary, at recommended levels of dietary calcium intake, neither an increase in cardiovascular or lithiasis risk, nor a negative association with the lipid profile, has ever been reported (recommendation 5).

The recommendations are divided into three categories, namely, positive recommendations (what we recommend), neutral recommendations (what we do not recommend), and negative recommendations (what we advise against).

The positive recommendations apply to Mediterranean-type diets and the consumption of dairy products (2 to 3 a day) in combination with "high quality protein" and calcium, and especially fermented dairy products (yoghurt, cheese). Considering the most recently published data, the consumption of at least 3 dairy products a day may be envisaged for institutionalised, dependent elderly individuals [22]. Lastly, calcium-rich mineral waters are also a good source of calcium, if daily consumption of dairy products is not enough to attain optimal calcium intake levels (recommendations 1, 4, 6, 7).

The neutral recommendations apply to pre- and probiotics, phytoestrogens, tea and coffee consumption, and vitamins other than vitamin D (recommendations 11, 12, 14, 15). Currently, there is not enough scientific data to specifically recommend their use in patients with osteoporosis or in the prevention of osteoporosis. The same is true of vitamin D-enriched foods and calcium-enriched plant-based beverages as replacements for vitamin D supplementation and dairy products, respectively (recommendations 6, 10). Lastly, the systematic use of high-protein, high-calorie ONSs cannot be recommended owing to a lack of scientific data demonstrating a beneficial effect on bone health (recommendation 8).

The negative recommendations apply to unbalanced Western diets, vegetarian and especially vegan diets, weight-loss diets in normal-weight individuals, alcohol consumption, even in moderation, and excessive soda consumption (recommendations 1, 2, 3, 12, 13).

In conclusion, these are the first set of recommendations addressing the role of diet in the prevention and treatment of osteoporosis. Updating them is essential, given the pace at which literature on the subject is being produced.

Disclosure of interest

EB occasional work (advisory boards): Nestlé.

JH, GL, MAL, SG, CA, RC, VC, PF, TT, JML, BC, JP declare that they have no competing interest.

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