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The role of low acid load in vegetarian diet on bone health: a narrative review

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Summary

Vegetarian and vegan diets contain low amounts of protein and calcium. For this reason they are supposed to cause low bone mineral density (BMD) and osteoporosis. But this is not the case, except for vegans with a particularly low calcium intake. The absence of osteoporosis or low BMD can be explained by the low acid load of these diets. Nutritional acid load is negatively correlated with bone mineral density (BMD) and positively with fracture risk. Low acid load is correlated with lower bone resorption and higher BMD. It is linked to high intake of potassium-rich nutrients, such as fruits and vegetables, as found in vegetarian diets. The total nutritional acid load, which not only depends on the potassium content of the nutrition, was recently assessed in several studies on vegetarian and vegan diets and was found to be very low or absent, while the diet of Western-style omnivores produces daily 50 to 70 mEq of acid. This might be an important factor for the protection of vegetarians from osteoporosis.

Key words: *vegetarian diet; vegan diet; bone health; low bone mineral density; osteoporosis*

Introduction

Vegetarian and vegan diets are usually poor in proteins and calcium. Both nutrients are necessary for the development and the maintenance of bone. Therefore it can be assumed that vegetarians and vegans have osteoporosis more often than omnivores, i.e. subjects who consume vegetables/fruit and meat products. In addition, there are other nutritional factors that may negatively influence bone health of vegetarians. Vegetarians often consume lower amounts of phosphorus, zinc, copper, vitamin B12 and vitamin K, nutrients which all have an effect on bone health [1]. Because these factors are quantitatively less important than proteins, calcium and potassium, and also less investigated in this context, they are not included in this review.

The assumption that vegetarians and vegans may have osteoporosis is relevant, because vegetarianism is increasing in the Western world. At least 2.5% of the Swiss population are vegetarian [2], and about 10% of them are vegans. It must be remembered that only vegans consume an exclusively vegetable diet, while vegetarians also consume dairy products (lacto-vegetarians), or eggs (ovo-vegetarians), or both (lacto-ovo-vegetarians), which improves their protein and calcium intake in comparison with vegans.

This narrative review analyses the literature on the influence of vegetarian and vegan diets on bone health and aims at explaining the published observations by the positive bone effect of a high potassium intake and a low nutritional acid load, as demonstrated by some recent studies. It is based on the newer literature since 2000. Of the earlier literature, only particularly significant studies on the relationship between vegetarian diet and bone density are reported. The few publications on the role of the nutritional acid load in vegetarians are probably fully captured in this review.

The particularities of vegetarian and vegan diets with respect to bone health

The low intake of calcium and protein

Compared with the diet of omnivores, the diets of vegetarians and especially vegans risk containing in general less protein, less calcium, less vitamin D and less of other nutrients that have a positive influence on bone health. On the other hand, they contain more potassium, and bear a much lower acid load, both being reported as positive for bone. Calcium and protein are consumed mostly, although not exclusively, in form of dairy products and meat. For this reason, the risk of calcium deficiency does not concern lacto-vegetarians. When the calcium intake is below 800 mg/day, the risk of hip fracture increases significantly [3]. Therefore, an intake of less than 800 mg/day is considered as low, at least for Caucasians and the Western world. A similar correlation with bone health was observed with protein intake below 10.8 g/microjoule, which means a mean protein intake of less than 1.24 g protein/kg bodyweight [4]. This is a surprisingly high limit. In general, only a protein intake of less than 0.8 g/kg bodyweight is considered as insufficient for bone health [5, 6]. This is also the minimal intake for an equilibrated nitrogen-balance in elderly individuals [7]. According to comparative studies, the average protein and calcium intakes of vegetarians and especially of vegans are below these limits (table 1). It has, however, to be remembered that the needs for calcium and protein can be covered with vegetables, as long as those with a high

content of protein and of bioavailable calcium are chosen. It can be concluded that vegetarians and vegan diets often contain lower amounts of protein and calcium than those of nonvegetarians. Therefore, vegetarians and vegans might be risk candidates for osteoporosis.

The high intake of fruit and vegetables

The vegetarian diet also has some characteristics that are positive for bone. Several studies have shown positive correlations between the intake of fruits/vegetables and BMD [8–10], and negative correlations for bone loss [9], although a major review found this association still questionable [12]. Most striking information came recently from a very large survey in nonvegetarians (over 1 million patient-years), which showed an increase in the risk of hip fracture when the intake of fruit and vegetables was below two servings/day, but no risk reduction in high consumers of fruit and vegetables [13].

This observation is in line with the results of a 2-year supplementation study with fruit and vegetables, which did not reduce postmenopausal bone loss [14]. Again, these subjects were not vegetarians. In addition, the dietary change was short. Cross-sectional studies showed more positive results than this intervention study, probably because they capture long-term or even life-long nutritional habits. Indeed, a review of the publications on the effect of fruit and vegetable intake on bone concluded that, among the few unbiased studies, the cross-sectional ones were those which showed positive correlations [15].

The positive effect of fruit and vegetables can be partially explained by the calcium-sparing effect of potassium [16]. A high intake of fruit and vegetables represents a high potassium-intake. A study in elderly women has shown that the women with the highest urinary excretion of potassium, and by implication with the highest intake of fruit and vegetables, also had the highest BMD [17]. But a very large epidemiological nutritional assessment of vegetarians by means of questionnaires did not show an increased potassium intake on the basis of the food questionnaires [18]. Since no measurements of the urinary excretion of potassium, the ultimate parameter for potassium intake, were performed, the results can still be questioned by smaller studies with urine measurements.

The low intake of acidifying nutrients

A further characteristic of vegetarian and vegan diets is their low acid load, which has a positive influence on bone health, as discussed later. It is partially linked to the potassium content of the diet, but depends on several ions, and can be assessed globally.

All these negative and positive influences of the vegetarian and vegan diets have to be considered when their effect on bone is evaluated.

The bone health of vegetarians

The reports on BMD in vegetarians go back to the eighties, are contradictory and are often not comparable. Some early studies found slightly decreased BMD in vegetarians, and explained this by low bodyweight [19]. Studies from the eighties found that the vegetarian diet reduces the bone loss with age. Vegetarian diet was even thought to protect bone. The authors explained this by "some factor associated with meat consumption" and already suggested, among others, that the absence of a nutritional acid load induced by meat could be responsible for that [20]. In Asian studies, the absence of low BMD in vegetarians was supposed to be due, at least in part, to phyto-oestrogens, although there is no proof for their effectiveness [21, 22]. A 2-year follow-up study showed that the bone loss over time was less in vegans than in omnivores, but the difference was not significant, probably because both groups had a low protein and calcium intake [23]. Another study found bone loss in the forearm similar in lacto-vegetarians and in omnivores [24]. A highly precise study on Buddhist nuns, who adhere to a strictly vegan diet, also showed equal BMD values in the nuns and in the omnivore controls, although the protein, calcium and calorie intake of the nuns was half that of the controls [25]. A review of 2004 confirmed that lacto-ovo-vegetarians did not have lower BMD than omnivores, despite their low protein and calcium intake [26]. It did not provide an explanation for this. It just mentioned that the very low intake of protein in vegans could have a negative effect on bone. Finally, the same author concluded in a review of 2009, that vegetarianism is not a risk for osteoporotic fractures [27].

However, a meta-analysis of nine studies demonstrated that the BMD at the femoral neck and lumbar spine, the most relevant sites of BMD measurement, was lower in vegetarians and vegans than in omnivores [28]. This is an apparent contradiction with the other observations, but the study almost exclusively considered vegans, who are more exposed to low protein and calcium intake than vegetarians. It also showed that vegans had a lower BMD than lacto-vegetarians, because of their lower protein and calcium intake. Indeed, in another study, vegans had a 3.9 times higher risk for osteopenia than lacto-ovo-vegetarians

Table 1: Daily calcium and protein intake of omnivores, lacto-ovo-vegetarians und vegans (mean values).

		Omnivores (Crowe, Appleby: meat eaters)		**Lacto-ovo-vegetarians**		**Vegans**	
Author	**Ref**	Calcium	Protein	Calcium	Protein	Calcium	Protein
Crowe	[58]	1 026 mg	87 g	1 019 mg	60 g	557 mg	58 g
Janelle	[63]	950 mg	77 g	875 mg	57 g	378 mg	52 g
Knurick	[48]	939 mg	97 g	746 mg	68 g	768 mg	69 g
Lau (China)	[46]	344 mg	60 g	384 mg	29 g	359 mg	35 g
Appleby women	[53]	995 mg	–	1 018 mg	–	586 mg	–
Larsson	[66]	1 328 mg	80 g	–	–	538 mg	55 g

Significance: Crowe: ANOVA p <0.001; Janell: Vegans versus omnivores: p <0.01, lacto-ovo-vegetarians p <0.05; Lau: lacto-ovo-vegetarians versus vegans p <0.05; Knurick: for protein adjusted p = 0.006 univariate analysis. Larsson: p <0.05 for protein and calcium.

or omnivores (corrected odds ratio [OR] 3.9; 95% confidence interval [CI] 1.2–12.8) [29]. Therefore, vegetarians have generally a normal or slightly decreased bone density, and vegans have a higher risk for osteoporosis than vegetarians.

All these studies relied on X-ray densitometry. One study using bone ultrasound at the calcaneum found 6% lower values in vegetarian men than in omnivores, and no difference in women [30]. Since this is the only ultrasound study, its results cannot be compared with the above quoted literature.

Calcium balance studies did not provide any explanation. Calcium balance of vegans was not significantly lower than that of lacto-vegetarians despite a 36% lower calcium intake [31]. The authors could not explain the phenomenon. An unknown factor, linked to the absence of meat consumption, or rather to the consumption of fruits and vegetables, seemed to be responsible for the surprisingly good calcium balance of vegetarians. Again, this could be the low acid load.

The impact of the nutritional acid load on bone health

The acid load produced by a Western-style diet corresponds to 50–70 mEq/day [23], which has to be buffered mainly through increased bone resorption, while alkalising food stimulates bone formation. This has been shown in animal and human research [33–35].

The nutritional acid load can be calculated according to two methods, the PRAL (potential renal acid load) [36, 37] and the NEAP (net endogenous acid production) [38]. Both parameters are expressed in milliequivalents (mEq/day).

The PRAL value indicates the acid or alkaline load provided by a certain food item, in mEq/100 g. The total load of meat depends, obviously, on the amount of the given food item consumed, and is calculated for each food item on the basis of its average composition concerning the most relevant PRAL-determining factors (see the formula), which include protein to estimate sulphate. A specific conversion factor is applied, which corrects the amount consumed by the average intestinal net absorption rate, the grade of dissociation, the molar valency and the atomic weight. The PRAL value can be taken directly from food tables, which indicate for each food item the PRAL value according to the average content of the determining substances or ions. This allows the PRAL to be calculated directly from dietary intakes. The PRAL value is calculated using the following formula:

PRAL (mEq/d) = 0.49 x protein (g/d) + 0.037 x phosphorus (mg/d) – 0.021 x potassium (mg/d) – 0.026 x magnesium (mg/d) – 0.013 x calcium (mg/d)

The accuracy has been tested mainly by measuring the urinary acid secretion [36].

Easier to apply is the NEAP, because it relies only on the acidifying action of proteins, mostly of the sulphate-containing amino acids of meat, and on the alkalising effect of potassium from weak organic acids [35]. The formula is:

NEAP (mEq/d) = (0.91 x protein g/d) – (0.57 potassium mEq/d) + 21; or = (54.5 x protein g/d / potassium mEq/d) – 10.2 [38].

According to these formulae, meat bears an acid load, while most fruits and vegetables have an alkalising effect.

Several cross-sectional studies have demonstrated the effect of the nutritional acid load on bone density. For example, a study in 1 056 women showed a negative correlation between the nutritional acid load and the BMD [39]. In another study in over 300 women a low potassium intake and high nutritional acid load went along with low BMD [40]. A recent summary of prospective studies on the bone effect of fruit and vegetable intake found a positive effect in three out of four studies [41].

Intervention studies showed that bone resorption was lowered by a diet rich in alkalising nutrients [42], as well as by a mineral water rich in calcium that is also rich in bicarbonate [43]. Orally administered bicarbonate improved the calcium balance [44], and the prescription of potassium citrate could even improve BMD in elderly persons [45].

Therefore, the alkalising effect of vegetarian and vegan diets may have a positive effect on bone, but this has been considered only in the recent literature.

The nutritional acid load of vegetarian diet

Table 2 summarises studies assessing the nutritional acid load of vegetarian and vegan diets in comparison with the omnivore diet.

An early study of 1998 [46] has shown that the bone mineral density (BMD) in the femoral neck in elderly vegans was lower than in vegetarians and omnivores, while that of the lumbar spine was not different. Although the acid load was not measured, it was assessed indirectly. In the vegetarians the BMD was correlated with the protein and calcium intake. The very low intake of protein allowed the assumption that the nutritional acid load was low. The observation that omnivores did not have a higher BMD than vegetarians remained unexplained, because the acid load was not considered. But the potassium excretion was measured. In vegans it was almost twice that of the omnivores, because of the high intake of fruits and vegetables. This means again that the nutritional acid load was low or absent.

Only recent studies included the assessment of the nutritional acid load in vegans. A controlled study in postmenopausal women reported that specific fruits and vegetables known for their positive action on bone (e.g. prunes, citrus fruits, onions, broccoli, Chinese cabbage, etc.) had a better effect on bone metabolism than common fruits and vegetables. This could mainly be explained by the difference in acid load. The average PRAL value with the specific fruits and vegetables was –23 mEq/day, i.e. alkalising, while it was almost neutral at –3 mEq/day in the control group [47].

Another study also found a very different acid load (PRAL) between omnivores and vegetarians or vegans: +19.6 mEq/day in omnivores, –1.5 mEq/day in vegetarians, and –15.2 mEq/day in vegans. The latter value indicates a definitely alkalising nutrition, which decreases bone resorption and favours bone formation [48]. It compensated for the nutritional deficiency of the vegetarians and vegans, who consumed on average only 69 and 68 g protein/day, respectively, (omnivores 97 g/day) and less than 800 mg calcium/day (omnivores 939 mg/day). A strongly alkalising PRAL

value of –39 mEq/day was also found in the nutrition of strict vegans in Germany [49]. The same was observed in another study: the acid load (NEAP) was lower in the vegetarian diet (31.3.mEq/day) than in the diet of omnivores (43.6 mEq/day), with the lowest value in the vegan diet (17.3 mEq/day) [50]. In general, it has already been reported that the more vegetarian a diet, the lower its acid load [51]. This can explain why the BMD is not decreased in vegetarians and in most vegans despite their low protein and calcium intake.

The fracture risk of vegetarians and vegans

The bone sparing effect of the vegetarian diet could go along with a decreased fracture risk. This is difficult to assess, because such a study would need large numbers of subjects, and the assessment of the nutritional acid load is a time-consuming procedure. With the Mediterranean diet, which is not vegetarian but close to it, a decrease of the hip fracture risk was observed in a very large epidemiologic study [52]. But a vegetarian diet differs from the Mediterranean diet by the total exclusion of meat and fish, and a vegan diet by the additional exclusion of eggs and dairy products. More specific, an English epidemiological study on vegetarians showed the same fracture risk for vegetarians and omnivores, as well as the same BMD values. In vegans, however, the fracture risk was increased by 30% [53]. The authors explained this by the protein and calcium deficiency of the vegans, because the fracture risk became equal when vegans with a very low calcium intake were excluded from the calculation. This would mean that the bone protecting effect of an alkalising diet vanishes when the calcium intake is very low. For this reason, recommendations have been formulated for stimulating the calcium intake in vegans [54].

Some studies reported contradictory results. In one of them, fractures of the wrist were less frequent in vegans than in meat-eaters. This was probably because of the high, but not assessed, acid load of the meat-eaters. However, among vegetarians, low protein intake increased the risk of wrist fracture [55].

In the study on Buddhist nuns already mentioned [25], vegans and omnivores showed the same fracture incidence, but it was relatively high in both (21% and 23%, respectively), probably linked to the low intake of nutrients in both groups.

It can be concluded that the fracture risk is not elevated in vegetarians despite the low protein and calcium intake, but that it is higher in vegans, especially in those with a very low calcium intake.

Obviously, other nutritional factors of vegetarian and vegan nutrition also exert some bone effects, such vitamin K, magnesium, zinc, iron, etc., but their influence on bone health is relatively weak in this context and partially less examined. The same applies to the low content in vegetarian diets of vitamin B12 and omega-3 fatty acids [56, 57]. Vitamin D from nutrition has only a marginal effect on bone health. But it must be mentioned, that plasma 25OH-vitamin D levels were lower in vegetarians and vegans than in meat eaters, and even lower than in fish eaters, which might contribute to the negative bone effect of a very low calcium intake in vegans [58].

It must also be remembered that some fruits and vegetables have specific positive effects on bone metabolism, which are independent of the alkalising action of vegetarian diets. For example, the consumption of onions [59], of tomatoes, berries, salads and green vegetables could be significantly correlated with lower bone resorption and higher BMD of

Table 2: Assessment of the nutritional acid load of vegetarian and vegan diets in comparison to omnivore diet. (Each study used different method of assessment. This explains the variability between the studies. But the relative differences between omnivores, lacto-ovo-vegetarians and vegans are consistent.)

Author	Ref	Parameter	Omnivores mEq/day	Lacto-ovo-vegetarian mEq/day	Vegans mEq/day		Significance
Knurick	[48]	PRAL[b]	9	–1.5	–15,2		0.001[h]
Ausman	[50]	NAE [b,c,d]	42.6	31.3	17.3		0.01[i]
Ströhle 2011	[49]				Moderate:	strict:	
		PRAL [b,d]	–	–	–46.5	–39.0	0.037[k]
		NEAP [e]	–	–	–6.19	+2.41	0.026[k]
		NEAP [g]	–	–	+16.3	+12.6	0.002[k]
Ströhle 2010[a]	[51]	NEAP [b,f]	95% animal food + 109	85% plant food – 186	–		–
Gunn	[47]	PRAL [b,d,g]	–3	mixed fruits + vegetables+ herbs: –17	Specific fruits and vegetables and herbs: –23		0.001[l]

NAE = estimated net acid excretion; NEAP = net endogenous acid production; PRAL = potential renal acid load

[a] Model B: animal-fat energy = 51% of animal-food energy, equivalent to 10% whole-body fat content

[b] According to Remer and Manz [36]

[c] Adapted by Michaud [67]

[d] According to Remer et al. [37]

[e] According to Frassetto 1998 [38]

[f] According to Sebastian et al. 2002 [65] refers to [36]

[g] According to Frassetto et al. [64]

[h] Non parametric Kruskal-Wallis test

[i] Analysis of variance

[k] Mann-Withney U-test

[l] One way ANOVA

the lumbar spine in humans [60]. Blue fruits, such as plums and blueberries were also shown to inhibit bone resorption and to increase BMD in humans [61, 62]. Therefore, some fruits and vegetables can contribute to the bone sparing effect of vegetarian and vegan diets independently from their acid content, but only if they are consumed regularly in significant amounts, which is unusual. The acid load is a more general parameter since it derives from the total habitual, possibly life-long, food intake. The role of phyto-oestrogens, present in some plants and vegetables, is questioned and hardly disputed in the literature on vegetarians, and for this reason is not included in this discussion. In addition, other life-style factors may contribute to the bone health of vegetarians and vegans. Although not analysed in this context, they must be mentioned: vegetarians frequently have a healthier life style; their prevalence of obesity is lower and smoking is less; they have often an increased level of physical activity compared to non-vegetarians. All these factors may also positively influence bone health.

Overview

The nutrition of vegetarians and vegans is often low in protein and calcium, which increases the risk of osteoporosis. Whereas lacto-ovo-vegetarians avoid this nutritional insufficiency, strict vegetarians are at risk, but their BMD is not decreased or only a little. Vegans, however, have in general lower BMD and an elevated fracture risk, unless their calcium intake is almost normal thanks to the choice of calcium-rich vegetables. The absence of osteoporosis in vegetarians and partially in vegans with a sufficient calcium intake can be explained, at least partially, by the alkalising effect of fruits and vegetables, which decreases bone resorption, as shown in preclinical and clinical studies, both cross-sectional and interventional ones. This interpretation of data is supported by a small number of new studies in vegetarians and vegans, while the important literature on the nutritional intake and bone health of vegetarians usually does not refer to this aspect. Thus vegetarians and especially vegans should be reminded to maintain a normal protein intake, with supplements if necessary, and to choose vegetables that are rich in bioavailable calcium. Presumably, the nutritional acid load will be part of future studies on the influence of vegetarian and vegan nutrition on bone health. This would support the importance of the nutritional acid load, not only in vegetarians, but also in omnivores.

Conclusion

Despite their low protein and calcium intake, the bone health of vegetarians and vegans is protected by the low acid load of their diet. Only vegans may have a decreased BMD and an increased fracture risk, and this concerns vegans who consume especially little calcium.

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