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Practice guidelines

Vegan diet in children and adolescents. Recommendations from the French-speaking Pediatric Hepatology, Gastroenterology and Nutrition Group (GFHGNP)

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ABSTRACT

The current craze for vegan diets has an effect on the pediatric population. This type of diet, which does not provide all the micronutrient requirements, exposes children to nutritional deficiencies. These can have serious consequences, especially when this diet is introduced at an early age, a period of significant growth and neurological development. Even if deficiencies have less impact on older children and adolescents, they are not uncommon and consequently should also be prevented. Regular dietary monitoring is essential, vitamin B_{12} and vitamin D supplementation is always necessary, while iron, calcium, docosahexaenoic acid, and zinc should be supplemented on a case-by-case basis.

1. Introduction

Over the past 10 years, veganism has attracted a considerable amount of interest in Western society. Initially limited to a minority of adults, veganism has now extended to the pediatric population. The main motivation is animal protection, but it is also driven by the pursuit of a health benefit, concern over the use of hormones and antibiotics in animals, or the excessive exploitation of environmental resources. When the health risks attributed to the consumption of animal products lead parents to impose this type of nutrition on their infants and children, mental orthorexia by proxy is raised.

2. Definitions

A vegetarian diet excludes all types of meat, meat products (cold cuts, sausages, etc.), fish, shellfish, and crustaceans. Several types of vegetarian diets exist: lacto-ovo-vegetarianism where eggs and dairy products are consumed, lacto-vegetarianism where eggs are excluded, and ovo-vegetarianism where dairy products are excluded. In extreme forms, we refer to veganism, a diet in which all meat, dairy, seafood, eggs, and honey products are excluded. Veganism is more a response to an ideology advocating a vegan diet as well as a fight against animal exploitation, prohibiting wool, leather, and silk, as well as any product that has been tested on animals. The macrobiotic diet corresponds to a vegan diet with the exclusion of certain fruit and vegetables; the food intake is made up of 50–60% of whole grains, vegetables, legumes, algae, and fermented soya products. There are many variations to these diets: some vegetarians will occasionally consume meat, fish or dairy products, these are known as flexitarians, and in the extreme, some vegans, called fruitarians, will only consume pulpy and dried fruits.

3. Epidemiology

While epidemiological data on eating habits in adults are now more widely available, they are still almost nonexistent in the pediatric population. Recent reviews of the eating habits of the general population has shown that 5% of North Americans are vegetarians and 3.7% claim to be vegans, the prevalence of vegetarianism is higher in Australia where it is estimated at 11.2% of the population with 0.02% vegans and most of all in India where 30% of the population is vegetarian, mainly for religious reasons. In

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Europe, the prevalence of vegetarianism is also increasing, estimated at 2% in France, but rising to 9% in Germany, 10% in Sweden, and 12% in the United Kingdom. It is estimated that the number of vegans has increased by 350% over the last decade [1]. In relation to children, only the North American organization, the Vegetarian Resource Group, has studied the food consumption of 1200 children aged 8–18 years and estimated that 1% of them are vegans [2].

4. Consequences related to a vegan diet

The consumption of a vegan diet exposes the pediatric population to multiple nutritional deficiencies, in particular, vitamin B_{12}, vitamin D, iron, calcium, eicosapentaenoic and docosahexaenoic acids, and zinc. Several international scientific societies have therefore ruled on the recommendations concerning veganism in children. Consequently, the American Academy of Pediatrics and the German Nutrition Society advise against a vegan diet in children [3,4]. In more recent recommendations, the Nutrition Committee of the European Society for Paediatric Gastroenterology, Hepatology and Nutrition (ESPGHAN) does not recommend this type of diet, but if the family so wishes, a dietary and medical framework with regular monitoring should be provided [5]. Similarly, the Italian Nutrition Society does not contraindicate this type of diet if dietary and medical care is provided [6].

There are few pediatric studies evaluating the nutritional deficiencies in vegan children compared to omnivore children and adolescents.

4.1. Protein intake

Children's protein needs are defined in Table 1 [7].

The vegan diet normally provides sufficient protein, except in young infants who are not yet fully diversified and only fed with an inadequate plant-based beverage. However, the quality of a protein, characterized by its digestibility and its essential amino acid content, must be taken into account.

Certain vegetable proteins such as soy proteins or gluten have the same digestibility as animal proteins, estimated at more than 95%. On the other hand, due to the presence of an envelope and antinutritional factors such as digestive enzyme inhibitors, tannins, phytates, glucosinolates, and isothiocyanates, naturally present in whole grains and legumes, these foods have lower digestibility by approximately 50–80%. Independently, this digestibility can be altered by food processing, which is responsible for the formation of inhibitory compounds, such as D-amino acids or lysinoalanine.

All the essential amino acids can be found in the vegan diet, but some are absent in certain plants, such as lysine in cereals, rice, and corn and methionine in legumes.

4.1.1. Infants

Studies have shown that the milk from vegetarian mothers is nutritionally adequate and allows for normal growth in the first 6 months of life [8]. There have been no studies in children born to women who are vegan. On the other hand, maternal milk from mothers on a macrobiotic diet is lower in protein than milk from omnivore women, but the consequences on child growth and development are not reported in the literature [9]. Some European and North American scientific societies therefore recommend a 10% increase in protein intake, which should be varied, during the second and third trimesters of pregnancy and during maternal breastfeeding [10].

In nonbreastfed infants, a rice protein-based infant formula supplemented with lysine, threonine, and tryptophan or a soy-based infant formula fortified with methionine after 6 months allows the child to grow similarly to children receiving a cow's milk protein-based infant formula [11]. On the other hand, unadapted plant-based beverages (whether soy, cereal, oilseed-based, etc.) should not be used because of the severe protein-energy deficiencies they induce [12].

4.1.2. Children over 6 months

Protein intake is generally reached in a vegan diet with the consumption of a variety of plants. The growth of young vegan children is regular, but they are often in the bottom quartile for body weight in the few available pediatric studies [13].

In the vegan children over 4 years of age, growth is also similar to that of omnivore children. Their protein intake, generally lower than the omnivore children, nonetheless meets European recommendations [14].

Table 1
Protein requirements assessed by the French Recommended Nutritional Intake (AFSAA 2001) and the French Population Reference Intake RNP (ANSES 2016) [7].

AFSAA		ANSES		
Children (years)	Protein (g/day)	Children, years	Protein intake Lower limit, % TEI	Protein intake Upper limit, % TEI
0–2	10	0–1	7	15
2–3	12	1–3	6	15
4–6	16	3–5	6	16
7–9	22	6–9	7	17
AFSAA		**ANSES**		
Adolescent boys (years)	Protein (g/day)	Adolescents	Protein intake Lower limit, % TEI	Protein intake Upper limit, % TEI
10–12	29	10–13	9	19
13–15	41			
16–18	50	14–17	10	20
AFSAA				
Adolescent girls (years)				Protein (g/day)
10–12				29
13–15				41
16–18				43

TEI: total energy intake.

4.1.3. Adolescents

The growth of vegan adolescents is also identical to that of omnivore adolescents, with a lower protein intake, but which also meets the French recommended nutritional intake (RNI) [15]. Although there are no specific studies evaluating the protein intake of vegan adolescents with the new French established criteria, the Population Reference Intake (PRI), it appears to be within the recommended range of between 10 and 20% of the total energy intake (TEI) [7].

4.1.4. Recommendations

Only infants who are primarily fed with an inadequate vegetable-based drink are likely to have a protein deficiency. On the other hand, the protein intake of vegan children and adolescents, although slightly lower than that of omnivore children, responds to the French RNI and PRI at their lower limit. As a result, the increase in protein intake, advocated by American dietetic societies does not seem justified [16]. However, since the digestibility of vegetable-based proteins is often lower than that of animal proteins and the content of certain essential amino acids is sometimes limited, it is necessary for vegans to consume a great variety of seeds and plants. Protein digestibility can also be improved by various processes. Legumes, cereals, potatoes, and tomatoes contain inhibitors of proteolytic digestive enzymes. These inhibitors can be inactivated by cooking. Seed germination leads to the production of enzymes that reduce phytates and improve digestibility. The fermentation of plant products can also improve digestibility.

Concerning the essential amino acids, lysine, which is deficient in cereals, can be provided by legumes or certain seed oils, and methionine, which is deficient in legumes, can be provided by most cereals.

4.2. Vitamin B_{12} requirements

The recommended vitamin B_{12} requirements are summarized in Table 2 [17]. Vitamin B_{12} is almost exclusively present in products of animal origin. It is absent in plants except in certain algae or fungi, but its bioavailability is often low and varies depending on the species. It should also be noted that algae are very rich in inactive vitamin B_{12}, which inhibits the absorption of active vitamin B_{12} [18]. Other foods, such as tempeh, can improve vitamin B_{12} status, but it is not a sufficient source for vegans.

Vitamin B_{12} supplementation is necessary in the case of a vegan diet, whatever the age. Vitamin B_{12} supplementation or addition in certain foods, in free form, has high absorption capacities, but the intrinsic factor, essential for absorption, is saturated beyond an intake of 2.5 μg per meal. It is estimated that the consumption of oral doses of 1 μg, 10 μg, 50 μg, 500 μg, and 1000 μg of cobalamin is absorbed with a capacity of 56%, 16%, 3%, 2%, and 1.3%, respectively [19].

4.2.1. Measurement methods

Because liver stores are sufficient for several years, a vitamin B_{12} deficiency develops slowly. As plasma vitamin B_{12} levels do not reflect a deficiency of the active form, a suspicion of vitamin B_{12} deficiency should be investigated by plasma homocysteine (normal < 10 μmol/L), holotranscobalamin II (normal > 45 pmol/L), and/or methylmalonic acid (normal < 271 nmol/L).

Table 2
Recommended nutritional vitamin B12 intake (in μg/day) [17].

Lactating woman	2.8
1–3 years	0.8
4–6 years	1.1
7–9 years	1.4
10–12 years	1.9
13–15 years	2.3
16–19 years	2.4

4.2.2. Breastfed infants

Women who have been vegans for several years, with little or no supplementation, expose their infants to a vitamin B_{12} deficiency if they are exclusively breastfed. Hematological or neurological disorders, anorexia, growth failure, involuntary movements, abnormal EEGs, or hyperpigmentation, mainly palmar or plantar, should lead to search for vitamin B_{12} deficiency. Several cases of anemia and developmental delay have been described in infants [20]. For breastfed children, there is a good correlation between vitamin B_{12} levels in breast milk and serum concentrations in infants [21]. For this reason, supplementation in women is all the more necessary, even more so since Pawlak et al. estimate that up to 62% of pregnant vegetarian women are deficient [22]. This supplementation must be carried out with the appropriate products, because standard vitamin mixtures are not always sufficient to prevent deficiency and some compounds such as vitamin C or copper can degrade cobalamin.

4.2.3. Children from 6 months to 3 years

In older children, since the high consumption of folates by vegetarians and vegans can mask the hematological signs of vitamin B_{12} deficiency, nervous system involvement is often the first sign of damage. A systematic review has shown that vitamin B_{12} deficiency can occur in up to 45% of vegan infants, especially those on macrobiotic diets [23]. From the beginning of complementary feeding, it is essential that vegan infants receive vitamin B_{12} supplements if they do not consume a rice- or soy-based infant formula. The vitamin B_{12} content of these infant formulas is effective in meeting the needs of these children.

4.2.4. Children from 4 to 10 years and teenagers

In children and adolescents, vitamin B_{12} deficiency can lead to cognitive deficits. There are reported correlations between vitamin B_{12} deficiency and fluid intelligence and divergent thinking [24]. The systematic review of the literature on vitamin B_{12} deficiencies induced by a vegetarian or vegan diet in adults and children by Pawlak et al. identified five pediatric studies out of the 40 included. In children and adolescents, the prevalence of vitamin B_{12} deficiency ranged from 0 to 33%, with diagnostic criteria and diets that varied considerably from one study to another [23]. While serum vitamin B_{12} levels are a poor reflection of the active form of the vitamin, it appears in the two longitudinal studies of vegan children that supplementation is provided in the majority of cases [13,25].

4.2.5. Recommendations

In infants, the consumption of a rice- or soy-based infant formula provides the necessary vitamin B_{12}. Vitamin B_{12} status should be regularly checked in infants breastfed by a vegan mother for possible initiation of supplementation. However, vitamin B_{12} supplementation in the form of cyanocobalamin is mandatory in vegans who are no longer breastfed or who no longer consume rice- or soy-based infant formula. Oral administration rather than parenteral administration is recommended in this context. Oral suspension preparations are used in infants and young children. The latter can also be used in older children and adolescents, but alternatives exist in tablet or capsule form. As absorption is less than 50%, the recommended daily dose by the European food safety authorities is at least 4 μg/day after 4 years of age.

In the event of vitamin B_{12} deficiency, a daily initiation treatment will be implemented, ideally also orally. Parenteral treatment will be administered in severe deficits if there is any doubt about compliance.

Table 3
Recommended systematic vitamin B12 (cyanocobalamin) supplementation in vegans [26].

	Single daily dose (μg)	Repeated daily dose (μg)	Weekly dose (μg)
Lactating woman	50	2 × 3	1000 × 3
Children > 6 months and < 3 years of age	5	1 × 3	
Children between 4 and 10 years of age	25	2 × 3	1000 × 3
Children over 11 years of age	50	2 × 3	1000 × 3

Table 4
Recommended supplementation in cases of vitamin B12 deficiency in vegans [26].

	Initiation treatment	Maintenance treatment
Lactating woman	Oral dose: 1000 μg/day for 1 month IM: 1000 μg/day for 7 days then 1000 μg/week for 1 month	Resume systematic supplementation (Table 3)
Children > 6 months and < 3 years of age	Oral dose: 250 μg/day for 1 month	
Children between 4 and 10 years of age	Oral dose: 500 μg/day for 1 month	
Children over 11 years of age	Oral dose: 1000 μg/day for 1 month IM: 1000 μg/day for 7 days then 1000 μg/week for 1 month	

PO: per os; IM: intramuscular.

No international consensus exists on the amounts of vitamin B_{12} to be administered as a supplement and in case of deficiencies. The suggested doses at different ages are summarized in Tables 3 and 4 [26].

4.3. Calcium intake

The calcium requirements of children and adolescents are summarized in Table 5 [17]. Adequate calcium intake is essential in the pediatric population because bone mineralization occurs only during the growth period, up to about 20 years of age. While the vast majority of calcium is provided by dairy products, some plants, such as legumes and nuts, contain significant amounts of calcium. However, its bioavailability is dependent on the levels of phytate and oxalate present in the food. Spinach and chard, for example, are rich in these compounds, which limit the absorption of the calcium they contain.

Compared to cow's milk, the bioavailability of calcium in soy juice (tricalcium phosphate) is 75%. On the other hand, the bioavailability of calcium in tofu or calcium in mineral water is almost identical to that of cow's milk.

Some equivalences of calcium intakes in different foods are given as examples in Table 6.

4.3.1. Measurement methods

Plasma calcium measurements alone are of no interest and must be combined with plasma phosphorus, calciuria, and phosphaturia measurements. In the event of abnormalities in calcium and phosphorus homeostasis, ionized calcium, vitamin D (25 (OH) D3) levels, and parathyroid hormone should also be measured. In case of suspicion of insufficient intake, a bone densitometry test is recommended to evaluate bone mineral density (BMD), because abnormalities in plasma calcium and phosphorus appear much later.

4.3.2. Infants

Children breastfed by a vegan mother consuming different plants are not exposed to calcium deficiency because she uses calcium from her bones to enrich her milk.

In nonbreastfed children, inadequate plant-based beverages should be avoided since most of them do not contain enough calcium. They may be exposed to severe hypocalcemia that can result in seizures [12]. The administration of a rice- or soy-based infant formula is the only possible alternative. However, calcium supplementation is necessary when the infant formula drinking volume is no longer sufficient to meet needs.

In infants who are not exclusively breastfed, the only study conducted in children aged 10–20 months on a macrobiotic diet found lower calcium levels compared to those of omnivore children [27].

4.3.3. Children and adolescents (4–18 years)

Study results are sometimes contradictory. Some studies found that among vegetarian children, calcium intake and BMD were similar to those of omnivore children, while others found that although calcium intakes were within the usual range, the BMD was lower than that of a reference population [14,28]. The most recent study comparing 53 prepubertal vegetarian children to omnivore children found a significant decrease in total and lumbar spine BMD Z-scores [29].

In vegan adolescents, calcium intake is reduced, with consumption reportedly up to three times lower than omnivore adolescents [30]. An earlier study had found that BMD was lower in adolescents on a macrobiotic diet compared to omnivores [31]. No

Table 5
Recommended nutritional intake of calcium [17].

	Calcium (mg/day)
1–3 years	500
4–6 years	700
7–9 years	900
10–19 years	1200

Table 6
Calcium equivalent example in some foods.

150 mL of cow's milk = 180 mg of element calcium	400 g of green vegetables 600 g of pulses 600 g of orange Approximately 350 mL of highly mineralized drinking water 50 g raw tofu 70 g almonds

Table 7
Recommended vitamin D supplements in children aged 0–18 years of age.

	Absence of risk factor	Risk factors[a]
Breastfed infants	1000–1200 units/day	
Children under 18 months receiving a vitamin D-enriched infant formula	600–800 units/day	
Children under 18 months receiving a nonenriched vitamin D infant formula	1000–1200 units/day	
Children from 18 months to 10 years of age and adolescents from 10 to 18 years of age	Two loading doses of 80,000–100,000 units in winter or a vial of 200,000 units	Quarterly loading dose of 80,000–100,000 units

[a] High skin pigmentation, absence of sun exposure in the summer, dermatological condition contraindicating sun exposure, cover clothing in the summer, digestive malabsorption, cholestasis, renal failure, nephrotic syndrome, certain drug use (rifampicin, phenobarbital, phenytoin), obesity, vegan diet.

studies in adolescents have indicated an increased risk of fracture due to this decrease in BMD, but a recent meta-analysis conducted in adults has confirmed that vegans have an increased risk of fracture [32].

4.3.4. Recommendations

Calcium intake in infants is mainly based on the consumption of rice- or soy-based infant formula. After diversification, as soon as the infant formula drinking volume becomes insufficient to meet calcium needs, supplementation is necessary.

In older children, the consumption of at least three plant-based products rich in calcium per day, low in phytate and oxalate (cruciferous vegetables, almond, sesame, leafy greens, soybean, tofu, tempeh), as well as the consumption of mineralized drinking water rich in calcium are recommended. However, given the high needs, calcium supplementation is almost always necessary, the prescribed amounts depend on dietary calcium intakes, particularly in the form of mineral water.

4.4. Vitamin D requirements

Vitamin D levels are dependent on exposure to sunlight and supplements. The recommended vitamin D intake is summarized in Table 7. Dietary intakes come almost exclusively from fatty fish and fortified products. In the absence of supplementation, vegan children and adolescents are particularly vulnerable to vitamin D deficiency. They are among the at-risk population. Therefore, a greater level of supplementation compared to the general population is necessary.

4.4.1. Measurement methods

The serum concentration of 25(OH)D or calcidiol is the best indicator of vitamin D status.

4.4.2. Infants

A previous study in infants aged between 10 and 20 months showed that vitamin D levels were lower in infants on a macrobiotic diet in comparison to omnivore infants, with a rickets prevalence of 28%, compared to 0% in the control group [27].

4.4.3. Children and adolescents

Ambroszkiewicz et al. recently demonstrated that the 25(OH)D3 levels in prepubertal vegetarian children were not significantly different from those in omnivore children [33].

In vegan adolescents, vitamin D intake was significantly lower than that of omnivores, especially among girls [30].

4.4.4. Recommendations

Supplementation should be the same for vegan children as for other children up to 18 months of age, given the presence of vitamin D in the rice- and soy-based infant formulas recommended at this age. After this age, a quarterly supplement is necessary, even outside winter periods. The 25(OH)D3 levels should be measured according to the supplements received.

4.5. Iron intake

The recommended absorbed iron requirements in the child and adolescent are summarized in Table 8 [17]. Vegetarian and vegan children's diets contain almost identical or even higher amounts of iron than omnivore diets. However, the bioavailability of plant-sourced iron is lower than that of heme iron from animal sources. It is estimated that the bioavailability of heme iron is 20–30% compared to 2–5% for non-heme iron [33]. Ascorbic acid (contained in citrus fruits, strawberries, kiwi, etc.) facilitates non-heme iron absorption by forming a chelate with ferric iron and reducing it to its ferrous form. Other organic acids found in fruit and vegetables such as citric, malic, lactic, and tartaric acids, carotenes, and retinol promote the absorption of non-heme iron. Similarly, soaking pulses activates phytases and reduces the number of bonds between phosphates and inositol hexa-phosphate (phytate), thus limiting the ability to sequester iron and subsequently increasing its absorption. Flour also promotes the activation of phytases.

4.5.1. Measurement methods

Several measurement methods can be used: hemoglobin testing for anemia, transferrin saturation to assess serum iron, soluble transferrin receptor to assess inflammation-related iron levels, and the ferritin blood test to assess iron stores are the most helpful in normal CRP conditions. Most literature studies in vegetarian and vegan children assess iron status by hemoglobin and serum ferritin levels.

4.5.2. Infants

During pregnancy and breastfeeding, all women are exposed to iron deficiency, most often requiring supplementation after careful monitoring of iron status [34]. Studies have shown that the

Table 8
Absorbed iron requirements of the child up to 17 years of age [33].

	0–6 months	7–11 months	1–3 years	4–6 years	7–11 years	12–17 years (boys)	12–17 years (girls)
Recommended requirements of absorbed iron (mg/day)	0.2	1.1	0.7	0.7	1.1	1.8	2.4

composition of the milk of vegetarian and vegan women is identical to that of omnivore women [9]. However, it should be recalled that a woman's milk is very low in iron and contributes very little to the needs of the infant before 4–6 months [33]. For example, a study conducted in breastfed infants indicated that the incidence of anemia was no higher at weaning before the age of 6 months, regardless of the mother's diet [35]. However, the findings in the literature are inconsistent. In the United Kingdom, one study found that young vegetarian infants aged 4–5 months had higher levels of hemoglobin and ferritin compared to omnivores [36]. This goes against the results of an earlier study conducted in the same country that found that vegetarian children under 3 years of age had a serum ferritin level $< 10\ \mu g/L$ in 64% of cases [37].

4.5.3. Children 4–10 years old

In older children, a recent systematic review of eight studies comparing the iron status of vegetarian children with that of omnivores found that the prevalence of iron deficiency was higher in vegetarian children in five studies. When hemoglobin was used as a marker, iron deficiency was observed in 18–47.5% of cases depending on the studies. When ferritin was measured, iron deficiency was observed in up to 73% of vegetarian children [38].

4.5.4. Adolescents

Vegetarian and vegan adolescents are exposed to iron deficiency. A Swedish study showed that iron ingested by vegan teenagers was identical to or even greater than their omnivore counterparts [30]. The results from a few investigations that studied the frequency of iron deficiency anemia are also sometimes inconsistent. The Swedish study mentioned above showed that among adolescent vegan girls, even though 20% had low ferritin (versus 13% among omnivores), only 6.6% had anemia due to iron deficiency, compared to 20% among omnivores. Other studies also found that, while within the usual standard, the iron levels and hemoglobin of Slovak vegetarian adolescents were lower than those of omnivore children [39]. This was confirmed in another study in a very heterogeneous vegetarian population aged 6–45 years: a higher prevalence of anemia and iron deficiency was observed than in the general population [40].

4.5.5. Recommendations

In vegan infants, the consumption of a rice- or soy-based infant formula in adequate quantities provides the necessary iron. It should therefore be encouraged for as long as possible, ideally up to at least 6 years of age. As soon as its consumption stops, their iron status should be regularly monitored in order to implement supplementation as quickly as possible in case of a deficiency.

In older children, iron-rich products (soybeans, beans, whole grains, hazelnuts, vegetable margarine, leafy green vegetables) with vitamin C-rich fruit should be offered with each meal. The methods of preparation, soaking, germination, grinding and the use of yeast promote iron absorption. Despite these dietary preferences, the risk of iron deficiency is clearly increased among vegans. However, it is possible that vegan children and adolescents who do not develop iron deficiency may have a genetic polymorphism of hepcidin/ferroportin that allows them to better absorb vegetable iron, while others abandon veganism as soon as the first symptoms of iron deficiency appear. This hypothesis could explain the low prevalence of iron deficiency in some of the above-mentioned studies, since the vegans included in these studies are probably among the individuals likely to absorb plant-based iron particularly well. A systematic serum ferritin dosage is therefore recommended before any iron supplementation. Particular attention should be paid to menstruating adolescent girls. In all cases, in the absence of supplementation, regular serum ferritin monitoring is necessary.

4.6. Zinc intake

In a normal diversified diet, half of the zinc intake comes from animal products. The plants that provide zinc are cereals, whole seeds, legumes, and nuts. However, as with other minerals, the presence of phytates and oxalates chelate zinc and limit its absorption. Some organic acids present in fermented products as well as sulphur-containing amino acids, peptides containing cysteine or hydroxy acids present in fruits could increase its absorption. Similarly, grinding, soaking, or fermentation to increase phytases also promotes zinc absorption.

Zinc deficiency in children is mainly associated with growth retardation, taste alteration, and susceptibility to infection. Severe deficiencies can lead to diarrhea and mucocutaneous damage, including perioral dermatitis and alopecia.

4.6.1. Assessment methods

The measurements used are erythrocyte, plasma, serum, and urinary zinc excretion assays. A decrease in serum alkaline phosphatases is associated with hypozincemia.

4.6.2. Infants

The zinc concentration in breast milk is relatively stable regardless of the maternal diet. As a result, the zinc status in children breastfed by vegetarian or vegan mothers is identical to that of children receiving milk from omnivore women [41]. Rice- or soy protein-based infant formula must be used as a relay, or in the absence of breastfeeding in vegan children. A recent literature review found that zinc levels were not significantly different between vegetarians and omnivores during dietary diversification and in the first 3 years of life. However, this study did not assess growth, cognitive development, and the occurrence of infections [42].

4.6.3. Children 4–10 years old

Few studies exist in children in this age range. Low zinc levels were found in Guatemalan vegetarian and vegan children compared to omnivore children, with the clinical consequences of poor growth and taste alteration [43]. However, another study in Taiwan found no difference in the zinc status and growth in vegetarian children compared to omnivores [44].

4.6.4. Adolescents

Treuherz demonstrated that despite increased zinc consumption in vegetarian adolescents compared to omnivores, the zinc concentration in hair was lower in the vegetarian group [45]. However, although conducted on small numbers, subsequent studies have found no difference in plasma zinc levels, infections, impaired growth, and pubertal development in vegetarian adolescents compared to omnivore adolescents [46].

4.6.5. Recommendations

In breastfed infants or infants receiving a rice- or soy protein-based infant formula, zinc intakes are sufficient to meet requirements.

Vegan children and teenagers need to eat a variety of plants to meet their zinc requirements. The consumption of zinc-rich foods should be proportionally higher for vegans than for omnivores due to the levels of phytates present in the majority of vegetables. For instance, vegetables of the *Brassicaceae* family (cabbage, turnips, mustard, radish, rapeseed, watercress, horseradish, etc.) should be consumed with fruit rich in organic acids. In the same way as for iron, foods prepared with soaking, grinding, and germination should be consumed regularly. The difficulties in following such a diet explain the increased risk of zinc deficiency among vegans. Zinc testing will therefore systematically be carried out in vegans, especially in young children, to check whether supplementation is necessary.

4.7. Iodine intake

Seafood products followed by dairy products are the richest in iodine. As a result, the absence of their consumption can result in thyroid deficiencies and dysfunctions. Vegans have mean iodine intakes estimated at 30 μg/day versus 110 μg/day and 130 μg/day, respectively, in omnivore children and adolescents [26]. These intakes are below the recommended intakes of 80 μg/day between 1 and 3 years of age, 90 μg/day between 4 and 6 years of age, 120 μg/day between 7 and 9 years of age, and 150 μg/day after 10 years of age.

4.7.1. Infants and children

There are no data in the literature on vegan children. The consumption of iodized salt is necessary for pregnant and especially breastfeeding women at a quantity of about 6.5 g of iodized salt per day to provide about 200 μg per day of iodine [47].

For infants, the addition of iodized salt is recommended once their diet has been diversified. After 1 year, the recommended intake varies from between 2 and 5 g per day depending on the scientific society [10,48].

4.7.2. Adolescents

There are no data for adolescents, but by extrapolation from studies conducted in adults, the daily intake of about 5 g of iodized salt seems appropriate.

4.7.3. Recommendations

Although the lack of consumption of animal products increases the risk of iodine deficiency, the possible use of iodized salts and currently available data do not justify iodine supplementation in vegans.

4.8. Eicosapentaenoic acid and docosahexaenoic acid intake

Seafood products are the main source of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). The only fatty acid of the omega-3 series present in plants are α-linolenic acid (ALA), which is mainly derived from chia seeds, flax, walnuts, hemp but also from walnut, rapeseed, and soybean oils. For EPA and DHA, the only possible sources for vegans are algae consumption. EPA and DHA can be synthesized from ALA, which requires sufficient amounts of ALA, but also proteins, pyridoxine, biotin, calcium, copper, magnesium, and zinc involved in DHA production. This synthesis also requires an optimal omega-6/omega-3 ratio because the synthesis of long-chain polyunsaturated fatty acids (LCPUFA) in each of these pathways uses the same elongases and desaturases. An excessively high omega-6/omega-3 ratio could mobilize these enzymes for the omega-6 pathway and consequently reduce the ALA conversion to EPA and DHA of the omega-3 pathway. The same applies to an excess of omega-9 (oleic acid) whose conversion to LCPUFA also uses the same enzymes. In view of this risk and the importance of DHA in children and adolescents, the French Food Safety Authority [49] and the European Food Safety Authority [50] recommend a minimum intake of DHA and/or EPA from 0 to 18 years of age. The French Authority has even qualified DHA as a semi-essential fatty acid. In the event of insufficient DHA intake, as is the case with vegans, oils rich in ALA should be preferred (walnuts, rapeseed, soy), while those with an excessively high linoleic acid/ALA ratio (peanut, corn, sunflower) and rich in omega-9 (olive) should be limited. Finally, it should be noted that the DHA concentration in breast milk depends on the mother's diet, as do the essential fatty acids, while the content of other fatty acids is independent of the maternal intake.

4.8.1. Infants

The breast milk of vegetarian women contains lower levels of DHA than that of omnivore women, but the birth parameters of newborns born to vegetarian mothers are no different [51]. However, it seems necessary that pregnant and lactating women with a vegan diet be supplemented with 100–200 mg/day of DHA, in the form of algae.

At initiation of diversification, oils rich in omega-3 (rapeseed, walnut, soybean) should be added to one to two meals a day, because DHA at this age is important in neurological and retinal development.

4.8.2. Children over 4 years of age

In vegetarian children compared to nonvegetarian children, one study found that the omega-6/omega-3 ratio was very high, with a higher amount of linoleic and adrenic acids and a lower amount of ARA (arachidonic acid), DHA, and EPA [52].

4.8.3. Adolescents

The weekly requirements for adolescents are 1.8 g of DHA [49]. One study found that vegetarian and vegan adolescents had higher levels of ALA compared to omnivores and a higher omega-6/omega-3 ratio. The EPA, DHA, and omega-3 levels remained low in this population [53].

4.8.4. Recommendations

For infants not consuming DHA-enriched plant-based infant formula, salty meals should be enriched with omega-3-rich vegetable oils (rapeseed, walnut, soybean). The problem will no longer arise when all infant formulas are fortified with DHA (in 2020). A supplement of 100 mg/day is recommended from age 1 year on. The consumption of algae, particularly two species rich in EPA and DHA, *Isochrysis galbana* and *Pavlova lutheri*, can help meet the recommended amounts.

The consumption of omega-3 in vegan children and adolescents should be ensured by foods rich in ALA (walnuts, flaxseed, hemp, and chia and their oils as well as rapeseed and soybean oils) and limited in foods rich in linoleic acid (corn, sunflower, and peanut oils). But to comply with the recommendations for a minimum intake of DHA and/or EPA up to 18 years [49], algae-based supplements are also required.

5. Summary of recommendations for vegan diets in children

A vegan diet is not recommended for infants, children, and adolescents due to the risk of nutritional deficiencies that are inevitable in the absence of supplements.

Protein intakes are in line with requirements, provided that the sources between cereals and legumes are sufficiently varied to ensure the essential amino acid requirements. The only exception are infants fed with an inadequate vegetable beverage.

In children who no longer consume rice- or soy-based infant formula, vitamin B_{12} supplementation is systematic; the dose depends on the child's age.

Calcium supplementation is necessary as soon as the consumption of rice- or soy-based infant formula decreases and in a routine manner in adolescents. The prescribed dose depends on other calcium intakes (mineral water, calcium-rich plants).

Vitamin D supplementation should be systematic, as in all children, but the doses should be those recommended for children at risk.

Table 9
Nutrition and nutritional supplements for the pediatric population exposed to a vegan diet.

	Lactating woman	Infants	Children	Adolescents
Protein	Varied consumption of vegetables and cereals as a result of reduced bioavailability of plant proteins and an unequal supply of essential amino acids depending on the plants consumed	Rice or soy protein-based infant formula	Varied consumption of vegetables and cereals as a result of reduced bioavailability of vegetable proteins and an unequal supply of essential amino acids depending on the plants consumed	
DHA	Oils rich in ω-3 100–200 mg of micro-algae/d	Infant formula enriched with DHA 100 mg of micro-algae/d	Oils rich in ω-3 100 mg of micro-algae/d	
Vitamin B_{12}	See specific tables with recommendations according to age			
Vitamin D	See specific tables with recommendations according to age			
Calcium	500–1000 mg/day depending on other sources	250–500 mg/day depending on other sources		500–1000 mg/day depending on other sources
Iron	Iron-rich plants with vitamin C-rich fruit Specific preparation methods (grinding, soaking, germination) 2–3 mg/kg of iron depending on serum ferritin	Rice- or soy protein-based infant formulas up to at least 6 years of age	Iron-rich plants with vitamin C-rich fruit Specific preparation methods (grinding, soaking, germination) 2–3 mg/kg of iron depending on serum ferritin	
Zinc	Plants rich in zinc (*Brassicaceae* family) Specific preparation methods (grinding, soaking, germination) If deficiency: 1 mg/kg/day of zinc gluconate	Rice- or soy protein-based infant formula	Plants rich in zinc (*Brassicaceae* family) Specific preparation methods (grinding, soaking, germination) If deficiency: 1 mg/kg/day of zinc gluconate	
Iodine	6.5 g/day of iodized salt	No addition of iodized salt required if consuming a rice- or soy protein-based infant formula	2–5 g/day of iodized salt	5 g/day of iodized salt

DHA: docosahexaenoic acid.

Iron supplementation will only be prescribed after confirmation of a deficiency by serum ferritin testing, which should be regularly monitored. The consumption of rice- or soy-based infant formula should be encouraged to last as long as possible, ideally up to at least 6 years of age.

Regular plasma zinc concentration dosing and monitoring will allow a decision to be made on possible zinc supplementation.

Regular consumption of iodized salts dispenses with iodine supplementation.

In infants, the consumption of an infant formula not enriched in DHA justifies favoring oils rich in ALA (rapeseed, walnut, soybean). In older children, systematic supplementation with EPA and DHA in the form of algae is necessary. Otherwise, the diet should favor foods rich in omega-3.

A summary of the various food supplement quantities required by the pediatric population exposed to a vegan diet can be found in Table 9.

6. Conclusion

Vegan diets that exclude all animal products from the food register are not adapted to the human species. The inevitable nutritional deficiencies they cause are particularly serious in children, as they will be adversely affected throughout their lives. It is therefore essential that children undergoing this type of diet be referred to competent health professionals who will prescribe the nutritional supplements essential to their dietary balance.

Disclosure of interest

The authors declare that they have no competing interest.

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