



Child growth and nutritional adequacy of plant-based diets

Tami Turner, Ph.D., RD

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Abstract

Background: The most common concern of children consuming plant-based diets, particularly vegetarian and vegan diets, is child growth and nutrient adequacy.

Objective & methods: Studies published in the past decade that assessed growth in children (of all ages) in developed countries were analyzed to determine the appropriateness of vegan and vegetarian diets in children. Case reports, studies that did not clearly define dietary patterns, and studies of highly restricted diets (strict raw food, macrobiotic) known to result in nutrient deficiencies were excluded. Guidelines and position statements on vegetarian and vegan diets from various reputable organizations were also reviewed.

Results: Studies suggest that vegan and vegetarian diets result in adequate growth in children. All diets, including omnivorous patterns, may be low in several nutrients, including vitamin D and calcium, and plant-based diets, including vegan and vegetarian diets, are at a higher risk for vitamin B12 deficiency (supplements are usually necessary).

Conclusion: The nutritional needs of growing children and adolescents can generally be met through a balanced, plant-based diet, but they require patient education.

Introduction

Plant-based diets include but are not limited to vegetarian and vegan diets. While these terms are common, the exact definitions vary within populations (e.g., flexitarian, Mediterranean, pescatarian, vegetarian, macrobiotic), resulting in large study heterogeneity. (1)

Synthesizing the data and providing overarching recommendations of plant-based for child growth and nutrient adequacy is challenging. It has been well-documented that very restricted diets, such as strict raw or macrobiotic diets, can result in faltered growth and nutrient deficiencies in children. (2–4) Thus, these and other highly-restricted diets are not recommended. However, many studies lump these extreme diets into the “vegan” category making it difficult, if not impossible, to differentiate if a balanced, mostly or exclusively plant-based diet is safe for children. Studies in children who consume plant-based diets that most closely resemble *balanced* vegan and vegetarian diets (as described in (5)) are also few and mostly cross-sectional, and those that measure growth in children in industrialized countries are rare. Furthermore, food fortification and available foods vary dramatically in different countries, making it challenging to summarize risk across regions. Nevertheless, the critical nature of adequate growth and nutrient adequacy in children consuming various dietary patterns highlights the need for accurate data to make evidence-based recommendations.

A narrative review is described herein on child growth and nutritional adequacy studies conducted in children in industrialized countries on plant-based dietary patterns, particularly focused on vegetarian and vegan diets

Methods

Medline was searched for studies in children of all ages from industrialized countries that included plant-based dietary patterns and child growth. Vegan and vegetarian diets were of most interest, but all dietary patterns that included or described plant-based diets were included unless extremely restricted diets (e.g., as strict raw vegan, macrobiotic, fruitarian) were the main focus or diets/ comparison groups were unable to be separated into vegan patterns that more closely resembled a balanced, recommended plant-based diet (such as described by Melina *et al.* (5)). Studies published in English in the past decade were included. Case reports and studies in children in developed countries were excluded. Keywords included such terms as vegan, vegetarian, plant-based diet, child, anthropometric, growth, nutrient intake, and nutrient status. The search was conducted from Nov 2022 to Feb 2023.

Due to the low number of studies that met inclusion criteria, older studies were reviewed to provide more information on the topic. Also, since several studies in this review reported specific nutrients that may be of concern in children's diets, regardless if they included animal products, reviews on the adequacy of these nutrients and markers of bone health in children consuming various plant-based diets were further researched. Finally, guidelines and position statements from numerous reputable organizations on vegetarian and vegan diets are summarized.

Results

Six studies met the inclusion criteria: one longitudinal cohort study in Canada, a retrospective study in Italy, and four cross-sectional studies in Germany, Poland, and Finland. (6–12) They are described herein.

Elliot et al. Vegetarian Diet, Growth, and Nutrition in Early Childhood: A Longitudinal Cohort Study. 2022. (6)

This longitudinal cohort study of Canadian children aged 6 months to 8 years (mean at baseline 2.2y; N= 8907, n= 248 vegetarians, with 10% as vegan) found no association between a vegetarian diet and zBMI or height-for-age z-score. Vegetarian children had higher odds of being underweight (i.e., <2 zBMI; 1.87 (95% CI 1.19, 2.96) p= 0.007); exploratory analysis of underweight children showed that they also tended to be younger and of Asian descent regardless of diet. (Note growth charts may overestimate underweight in Asian American populations, and the small sample size prohibited meaningful subgroup analyses).

Serum ferritin, vitamin D, and lipids did not differ by diet group. However, serum lipids (LDL, total, non-HDL cholesterol) were lower in children who did not consume milk.

Strengths include the longitudinal design, robust measurement tools (e.g., WHO standardized growth charts, biomarkers), and analyses that accounted for numerous clinically-meaningful confounding variables. Limitations include a relatively short follow-up time (2.8 y).

Conclusion: Vegetarian diet in early childhood results in normal growth compared to an omnivore diet. Nutrient status, including iron and vitamin D, did not differ by dietary pattern. However, children consuming vegetarian diets, very young ones, may be at higher risk of being underweight.

Ferrara. Length-weight growth analysis up to 12 months of age in three groups according to the dietary pattern followed from pregnant mothers and children during the first year of life. 2021. (7)

A retrospective study in Italy compared vegan, vegetarian, and omnivore diets and infant growth during the first year of life (n= 63) with consideration of maternal dietary patterns during pregnancy (n= 55)).

There were very slight differences in weight and length in infants of mothers with vegan than omnivore dietary patterns, but all babies were within healthy population growth parameters regardless of diet (e.g., WHO growth charts). For example, length was around the 50th percentile for all babies at 12 months (i.e., vegan at the 47th percentile, and vegetarian and omnivore at the 55th percentile). Note that more vegan mothers exclusively breastfed than omnivore mothers, which can influence growth rates. There were no differences in head circumference between groups.

A much higher proportion of vegan (95%) and vegetarian (84%) mothers consumed supplements during pregnancy than omnivores (27%), and more infants in the vegan (95%) and vegetarian group (76%) were supplemented than the omnivore group (66%). There were no statistical differences in anthropometric measures between maternal diet groups.

Strengths include considering the type and length of maternal dietary patterns and using validated food questionnaires and standardized growth charts. Limitations include parent-reported child anthropometric data, the unclear criteria for excluding highly restrictive diets, such as macrobiotic, raw, and fruitarian diets (not recommended due to the high risk of nutrient deficiencies), and small sample size.

Conclusion: Although there were very slight differences between groups, infant growth was adequate regardless of diet. Vegan and vegetarian Italian mothers studied herein were likely to use and provide supplements to their infants, indicating high nutrition awareness.

Weder, et al. Energy, macronutrient intake, and anthropometrics of vegetarian, vegan, and omnivorous children (1–3 years) in Germany (VeChi Diet Study). 2019. (8)

Weder et al. Intake of micronutrients and fatty acids of vegetarian, vegan, and omnivorous children (1–3 years) in Germany (VeChi Diet Study). 2022. (9)

This cross-sectional study of 1 to 3-year-old German children compared 127 vegetarian, 139 vegan, and 164 omnivorous children and found no significant differences in anthropometrics (weight-for-height, height-for-age, weight-for-age) even after adjustments for many covariates. Energy intake, dietary energy density, and macronutrient intake did not differ between groups, and all groups had moderate numbers of children not meeting their energy needs (28-42%, highest in omnivores).

Food diaries suggested that all groups did not meet calcium, vitamin D, or iodine recommendations with or without supplement use (although iodized salt intake was not recorded). Although higher in vegetarian and vegan groups than omnivores, iron intake may be sufficient to meet recommendations in all children. However, the lower bioavailability of plant-based iron may increase iron needs from vegan and vegetarian diets. Without vitamin B12 supplements, the vegan and vegetarian group fell short of intake recommendations, and vitamin B2 intake was low in the plant-based groups whether or not supplements were used (grains are not

fortified in Germany). Overall, vegans had the highest intakes of other micronutrients reported.

Stunting in 6% of children on a vegetarian or vegan diet was reported, which may be explained by extremely low-calorie intake, SGA, being exclusively breastfed for 7 and 9 months, and having parents with below-average height. About 4% of children (vegan and omnivore) were classified as wasted (1 being very tall). The omnivore group had a higher proportion of at-risk/overweight children (23% vs. 18%). These sample sizes, however, could not allow for statistical analysis between groups to assess the impact of diet on the prevalence of stunting or wasting, and group analyses indicated no differences in anthropometrics between groups based on diet.

Strengths include proper anthropometric measures (i.e., weight-for-height) and analyses with and without supplements. Limitations include some parent-reported weight, cross-sectional design, self-reported dietary and supplement intake, and discussions of inane differences (e.g., between-group contrasts for nutrients that were not statistically significantly different and fell within recommendations).

Conclusion: Vegetarian and vegan diets in early childhood can provide the same amount of energy and macronutrients as omnivorous diets, leading to normal growth. Calcium, vitamin D, and iodine (and possible iron in very strict plant-based diets) should be monitored in all children, and vegan and vegetarian diets should include vitamin B12 supplements. Because some countries do not fortify grains, vitamin B2 may be of concern in these areas.

Alexy, et al. Nutrient Intake and Status of German Children and Adolescents Consuming Vegetarian, Vegan or Omnivore Diets: Results of the VeChi Youth Study. 2021. (10)

This cross-sectional study of 6 to 18-year-old German children (mean 12.7 ± 3.9 years) compared anthropometric measures and dietary intake and status between children consuming a vegetarian (n= 149), vegan (n= 115), and omnivorous (n= 137) diet. There were no significant differences between groups for anthropometrics (height, weight, BMI-SDS) or energy intake. All groups met or exceeded protein intake recommendations, and all macronutrients fell with requirements (except omnivores did not meet fiber recommendations).

More than half of all children used supplements, with the highest use among vegans followed by vegetarians; however, micronutrient intake analyses did not include supplements. Nevertheless, all intakes of micronutrients were within the range of recommendations, except vitamin B12 and calcium (including omnivores). Blood biomarkers suggested B12 deficiency was likely in about 13% of vegetarians, 8% of vegans, and 4% of omnivores. Few children had low ferritin ($\leq 10\%$), but 28-36% of all children had low vitamin D levels, and roughly half of all children had low vitamin B2 levels (grains are not fortified in Germany).

Strengths of the study include the use of blood biomarkers and the moderate sample size. Limitations include the cross-sectional design, not including supplements in dietary intake analyses, and the use of self-reported 3-day weighed home food records/online questionnaire (vs. more accurate multi-pass dietary recalls).

Conclusion: Children and adolescents consuming a vegan or vegetarian diet grow similarly to those consuming an omnivorous diet. Calcium, vitamin D, B12, and B2 intake and/or status were low in many children, regardless of diet, particularly in vegans who did not use supplements. Note that Germany does not fortify their grains as is done in the US and numerous other countries.

Desmond. Growth, body composition, and cardiovascular and nutritional risk of 5- to 10-y-old children consuming vegetarian, vegan, or omnivore diets. 2021. (11)

A cross-sectional study of 5 to 10-year-old Polish children consuming omnivorous (n= 72), vegetarian (n= 63), or vegan diets (n= 52) compared anthropometric, dietary intake and status, physical activity, cardiovascular, and bone health.

Anthropometrics: The vegan group was shorter than the omnivore group (height z-score difference -0.57, or an estimated 3 cm), although age distribution did not appear to be accounted for (i.e., did not use height-for-age z-score). Because differences were reported and not actual values, whether these children followed a normal growth trajectory or were within the average distribution of population heights is unknown. Children consuming a vegan diet had lower BMIs than children on an omnivore diet (-0.53 BMI-z-score) and were leaner (e.g., skinfold measures). The clinical significance of these differences is unknown as actual values for BMI were not reported.

Dietary intake and status measures: Although some difference in nutrients were reported, there were no meaningful differences between groups for energy, protein, or other macronutrients (i.e., all are within

recommendations), except omnivores did not meet fiber recommendations and overconsumed saturated fat. Calcium intake was low in all groups, especially children consuming a vegan diet. Vitamin D intake was also very low in all groups, particularly those on a vegan diet without supplementation (~65% of all children did not take supplements, and milk is not fortified in Poland). Finally, vitamin B12 intake and status were lowest in children consuming a vegan diet if not supplemented.

Markers of health: Children on a vegan diet had 3.7 to 5.6% lower bone mineral density measures than children consuming an omnivorous diet, but these differences may not be clinically significant. On the other hand, the vegan group had the most favorable cardiovascular measures. Physical activity did not differ between groups.

Strengths include strong measures of physical activity, cardiovascular and bone health (e.g., DEXA), and stratifying micronutrients by supplement use. Limitations are the cross-sectional design, small sample size, parent self-reported dietary intake (food diary), unclear statistics to address age distributions when comparing height between groups (height vs. height-for-age z-scores), and the lack of actual values to make meaningful interpretation of most differences between groups (e.g., when all values fall within normal range but only differences are reported).

Conclusion: Compared to omnivores, consumption of vegan diets was associated with a healthier cardiovascular profile, increased risks of calcium, vitamin D, and B12 inadequacies if not supplemented, slightly lower bone mineral content, and possibly lower height (see limitations).

Hovinen et al. Vegan diet in young children remodels metabolism and challenges the statuses of essential nutrients. 2021. (12)

This cross-sectional study of 40 Finnish children (median age 3.5 y) consuming vegan (n= 6), vegetarian (n= 10), and omnivorous (n= 24) diets compared anthropometrics, nutrient status, and intake. There were no differences in height (z-scores, corrected for age and gender), BMI-SDS, or upper arm circumference (MUAC z-scores) between groups. The vegan group had lower vitamin A status based upon RBP, but none of the children were deficient after controlling for inflammation. Other nutrients (energy, protein, iron, iodine, folate, zinc, vitamin D, B12, saturated fat) either did not differ between groups and/or were not clinically meaningful (e.g., values were within recommendations/normal ranges).

Strengths included the clear assignments of dietary patterns based on food records (vs. self-report) and strong anthropometric measures. Limitations included extremely small and unequal sample size, cross-sectional design, and inane comparisons between groups (e.g., not clinically meaningful or values were within recommendations/ normal ranges).

Conclusion: Finnish children consuming vegan and vegetarian diets grow similarly to children on omnivorous diets. As food fortification and supplement use vary widely in different populations, some micronutrients, such as vitamin A, may be lower in some diets.

Older studies on vegetarian and vegan diets in children

Older studies on vegan and vegetarian diets during childhood are highly heterogeneous, mostly cross-sectional, often use small sample sizes, and the majority use inaccurate and growth charts that are outdated and based primarily on formula-fed white infants. Definitions of vegan and vegetarian

diets often vary. Overall, the majority of studies show that children have adequate growth compared to available growth charts.

Examples include:

- In a longitudinal study of matched pairs of English vegetarian and omnivorous children (7-11 y; N= 100), both groups lay close to the 50th percentiles for height and weight (published in 1997). (13)
- A mixed-longitudinal study in the Netherlands (published in 1994) of matched pairs of 418 macrobiotic (severely restricted diet) and omnivorous infants reported deficiencies of energy, protein, vitamin B-12, vitamin D, calcium, and riboflavin, retarded growth, fat and muscle wasting, and slower psychomotor development. (2)
- A prospective study of 20 vegan children in the UK published in 1992 reported normal growth. The children tended to be leaner and calcium intake was low (2 children also had low vitamin B12 intakes). (14)
- A 1990 US study of 2272 vegetarian children aged 6 through 18 found that the mean height and weight were at or above national reference values. (15)
- A 1989 study of 4-month to 10-year-old children (N= 404) living in a US collective community found children's height-for-age, weight-for-age, and weight-for-height within the population 25th-75th percentile reference range. (16)
- A prospective cohort study of 37 vegan children in the UK (published in 1988) reported that height, weight, chest, and head circumference

were within normal range; education and physical development measures were also normal. (17)

- A 1983 study of 142 vegetarian children (0 - 6 y) reported lower height (1-2 cm) and weight (0.5-1 kg) compared to reference populations, especially when the diets were severely restricted (e.g., macrobiotic), Energy intake, but not protein, was below recommendations. (18)

Iron, zinc, calcium, vitamin D, and bone health in children

Zinc

A review of zinc in infants and young children from industrialized countries (19) suggests there are no differences in serum zinc or growth between young vegetarian and omnivorous children, and there is insufficient evidence to conclude that a well-planned vegetarian diet cannot meet the needs for zinc for young children. However, as the bioavailability of zinc from plant foods can be lower, zinc needs can be higher for an exclusively plant-based diet.

Iron

In two reviews on iron in young children, the prevalence of iron deficiency was higher in omnivores in some studies, but in other studies, vegetarians had a higher iron deficiency. (19,20) Study heterogeneity was large, and the degree of deficiency varied considerably from one study to another. In the studies described herein, iron intake and/or status were similar for plant-based and omnivorous diets. As iron deficiency and iron-deficiency anemia in children are public health concerns in most countries, including the US, (21) it is important to assess and monitor iron intake and status in all

children. Notably, children from underprivileged households may be at a higher risk of deficiencies because of non-dietary factors (e.g., chronic inflammation).

Calcium, vitamin D, and bone health

In the studies described herein, calcium and vitamin D inadequacy were common among all diets, with vegans sometimes at a higher risk for insufficiency. In the US, calcium and vitamin D inadequacy is common with most diets. (22) Therefore, supplements/fortified foods with calcium and vitamin D may be needed for many children, particularly teenagers, minorities, and underserved populations. (23)

Reviews on bone health and fracture risk in vegetarians/vegans have yielded inconsistent results, which may be attributable to small sample sizes, differences in types of diets studied, and failure to control for confounders, such as physical activity level and nutrient intake. For example, in several reviews (including children, but most studies are in adults), vegetarians appear to have similar bone mineral densities and fracture rates as non-vegetarians when adequate calcium intake and good protein sources are included in the diet. (23–25) However, in one review of adults, older vegan adults (> 50 years) had higher fracture rates, and older vegan and vegetarian adults (>50 years) had lower bone mineral densities than omnivores. (26)

Because gains in a child's bone mass are highly variable, even in children of the same age and sexual maturity, (23) adequacy of calcium, vitamin D, protein, and other nutrients (B12), as well as physical activity throughout childhood, is of utmost importance. Thus, educating parents on the importance of diet on growth should occur in all children.

Guidelines and position statements

Guidelines worldwide highly recommend that all children and adults increase their intake of whole-plant foods to improve diet quality and reduce the risk of chronic diseases. (22,27) The Dietary Guidelines for Americans, Canadian Guidelines, and Australian Guidelines support plant-based dietary patterns to meet the nutritional needs of children. (22,28,29) The Academy of Nutrition and Dietetics (AND), (5) the German Society for Pediatric and Adolescent Medicine, (30) the Canadian Paediatric Society, (31) and the Italian Society of Human Nutrition (32) also state that the nutritional needs of growing children and adolescents can generally be met through a balanced, vegetarian diet, but they require planning and patient education. On the other hand, some professional groups do not support a vegan diet, including the German Nutrition Society, as several nutrients (e.g., B12, DHA, iron, iodine) may be challenging to obtain from food alone (Germany does not fortify foods except table salt). (33) However, AND (formally American Dietetics Association) and the Australian Dietary Guidelines state that well-planned vegan diets are healthy and appropriate for all ages and life stages, but supplementation of B12 is usually needed. (5,29) In addition, a recent NIH study (2022) modeling the American food system indicates that when the current vegetarian diet recommendations in the Dietary Guidelines for Americans are slightly modified, a vegan diet can provide adequate nutrients (at least in adults). (34)

Conclusion

In the last ten years, only a few studies in developed countries have measured growth in children consuming plant-based diets and were mainly conducted in Europe (where food availability, fortification, and RDAs are

different than in the US). In nearly all studies, child growth was similar when consuming vegan, vegetarian, or omnivorous diets. Children on plant-based diets are often leaner than their peers and at lower risk for overweight and obesity. Only 1 study (11) suggested slightly lower height in vegan children, but they may not have adjusted for age or gender and did not provide actual values to make clinically meaningful comparisons (i.e., height-for-age z scores not provided). Low calcium and vitamin D intake in all diets is commonly reported, particularly in countries that lack fortified foods, and calcium and vitamin D are considered nutrients of public health concern in the US (all typical diets (22)).

The remaining studies are typically much older (the 1970s-90s) and use outdated growth charts based on formula-fed white children. The food environment has dramatically changed since then, and more plant-based and fortified foods and supplements are available to the public, especially in the US. Nevertheless, numerous older studies suggest children have adequate growth with a vegan or vegetarian diet. Note that macrobiotic, fruitarian, and other overly-restrictive and fad diets are sometimes placed into the vegan category but are usually not assumed as "vegan" in most current scientific literature, and these diets have been shown to result in nutrient deficiencies and delayed/depressed growth and children. Thus, severe dietary restrictions are not recommended due to the very high risk of nutrient deficiencies.

Reviews on vegetarian and vegan diets in children typically report adequate growth, lower obesity risk, higher-quality diets, and better ability to meet dietary recommendations than those eating a Western diet. (1,35) Vitamin B12, calcium, and vitamin D are typical concerns, especially with vegan diets. Furthermore, a systematic review reported that the use of animal-sourced foods has been inconsistent in improving growth in children of developing

countries, with many studies showing no improvements in measures of height or weight. (36) Thus, it is essential to consider the diet as a whole for nutritional adequacy versus focusing specifically on the use or lack of animal-sourced foods, particularly in young children, as meat intake is a tiny proportion of the diet in all children (e.g., <1-8% in US infants (19)).

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In conclusion, studies suggest that vegan and vegetarian diets during childhood result in similar growth as omnivorous diets. All diets have the potential to contain inadequate nutrients. Some children had insufficient intake of calcium, vitamin D, and sometimes iron or iodine, regardless of whether animal-sourced foods or supplements were included. A plant-based diet, including a vegan and vegetarian diet, is particularly at high risk for vitamin B12 deficiency, and supplements are necessary. In countries lacking food fortification, other micronutrients may be of concern in some children (e.g., vitamin A, B2). Thus, all diets should be balanced and critical nutrients monitored, especially when foods are restricted or eliminated.

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