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REPRODUCTIVE, FEMALE AND CHILD HEALTH

REVIEW

Vegetarian diets and global disparities in calcium intake in pregnant women: A systematic review and meta‐analysis

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Abstract

Background: Vegetarian diets are currently experiencing increasing popularity and are also becoming more common in pregnant women. Calcium plays a crucial role for skeletal health and for physiologic processes during pregnancy for the mother and foetus.

Aims: Our study aimed to evaluate calcium intake of vegetarian versus nonvegetarian expectant mothers.

Materials and Methods: We searched PubMed and retrieved seven studies (six prospective cohort and one cross‐sectional) for inclusion in our random‐effects meta‐analysis. We calculated standardised mean differences (SMD).

Results: Results showed a significantly higher calcium intake in vegetarian than nonvegetarian pregnant women [SMD: 0.25; 95% confidence interval (CI): 0.14, 0.36].

Discussion: Most studies showed that the recommendations for calcium intake during pregnancy (ranging from 700 to 1200 mg/d) were met. Both vegetarian and nonvegetarian pregnant women showed higher calcium intakes in Europe and North America than in Asia. Serum calcium levels did not differ between vegetarian and nonvegetarian pregnant women (SMD: − 0.15; 95% CI: −0.42, 0.11), confirming that the tight regulation of calcium metabolism is not affected by dietary calcium intake.

Conclusion: To prevent inadequate calcium intake potentially associated with adverse gestational outcomes, we recommend adherence to existing recommendations by means of calcium supplementation (1.5–2 g/d), food fortification strategies, or behavioural interventions.

KEYWORDS

calcium, dietary minerals, maternal nutrition, pregnancy, vegetarian diet

INTRODUCTION

In recent years, vegetarian and vegan diets have gained substantial popularity. Approximately 5%–10% of European and US populations are vegetarians and nearly 3% are vegans, with an upward trend.[1] Most vegetarians are female and of child‐bearing age, implying that a sizeable number of pregnant women follow a vegetarian, and possibly, vegan diet.[2]

Whether meatless diets result in micronutrient deficiencies in pregnant women is controversial.[3] For example, current Dietary Guidelines for Americans do not provide explicit recommendations for pregnant women who adhere to a vegetarian or vegan diet.[4] By comparison, the American Academy of Nutrition and Dietetics advocates a plant‐based, including vegan, diet during pregnancy, while the German Nutritional Society does not recommend a vegan diet during pregnancy.[5]

The consumption of foods dense in vitamins, trace elements and minerals is essential for both maternal and foetal health.[3,6,7] During pregnancy, the most crucial micronutrients are folic acid, iodine and iron.[6] Pregnant women following a plant-based diet should also ensure adequate intakes of vitamin B_{12}, docosahexaenoic acid (DHA), calcium and zinc. Calcium specifically plays a major role for the mineralisation of the foetal skeleton, especially during the last gestational trimester and thus, contributes to normal foetal growth. As insufficient calcium is linked to hypertensive disorders like pre-eclampsia that is associated with an increased risk of maternal mortality and severe foetal outcome the WHO recommends daily calcium supplementation to prevent those morbidities.[8–13]

The assumption that dietary calcium intake of vegans is below calcium status compared to vegetarians and omnivores in nonpregnant women and men of different ages is described by various studies.[14–16]

However, to the best of our knowledge, the available data on calcium status in women following plant-based diets during pregnancy have not been quantified in a meta-analysis.

To fill this research gap, we conducted a systematic review and meta-analysis of studies that compared calcium intakes and serum calcium levels of vegetarian pregnant women with their omnivorous counterparts.

METHODS

The current systematic review and meta-analysis was based on the reported recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) statement.[17,18] The PRISMA Checklist provides a detailed overview of the procedures followed (Supporting Information: Appendix S2).

Search strategy

We searched PubMed using search terms referring to pregnancy, calcium measurements and vegetarianism. Supporting Information: Appendix S1 shows a detailed list of search terms. In addition, we searched lists of references of articles included in the current review.

Definition of forms of diet (exposure)

Participants were considered following a vegetarian diet if they consumed animal-derived products except for meat, or if they consumed meat less than once a month. Participants were considered following a vegan diet if they did not consume meat or animal-derived products but, rather, consumed plant-based food only. Nonvegetarian pregnant women were considered following an omnivorous diet and served as the comparison group.

Inclusion criteria

Studies were considered eligible if they investigated the relation between a plant-based diet and calcium status during pregnancy. We considered studies that followed an observational study design (cohort, cross-sectional and case-control), adequately reported calcium values (daily calcium intake, serum calcium and urinary calcium) were published in English or German language and included clinically healthy pregnant women with 'normal' pregnancy physiology without evidence of intestinal malabsorption.

Exclusion criteria

We excluded articles if the type of publication was inadequate (narrative review, guideline and position paper). In addition, we excluded intervention studies because in such studies, exposure to a plant-based diet during pregnancy was too short to reflect long-term, usual diet. Furthermore, we excluded studies that reported calcium measurements of participants who did not follow a meatless diet, and studies that provided incomplete data [i.e., no standard deviation (SD)].

Data extraction

Data extraction was carried out by M. K. and C. J. in duplicate. We extracted the following data from each study: name of first author, year of publication, study design, and study region; type of diet (vegan, vegetarian or omnivore), characteristics of participating population (sample size of the dietary groups, gestational age at study assessment) and calcium measurements (daily calcium intake in mg/d, serum or urinary calcium concentrations in mmol/L). Studies were used for quantitative analysis if the mean and standard deviation of calcium values were included or could be calculated from the data. We converted calcium values reported as interquartile range (IQR) into the mean and SD using the method by McGrath[19] and we transformed reported standard errors (SE) into SD. If available, additional information on the study population was extracted, including maternal age, religion, use of dietary supplements, duration of vegetarianism (long-term when following a vegetarian diet for more than 5 years), and self-declared or externally assigned dietary status.

Statistical analysis

We pooled mean values of daily calcium intake and serum calcium concentration and we performed random-effects meta-analysis when at least two studies presented calcium values. We did not pool studies of urinary calcium excretion because there was only one available study on urinary calcium and that study did not include a control population.[20] Data of semi-vegetarians were not taken into consideration in the current paper as no generalised definition could be derived from the corresponding studies.[21,22] Neither did we pool vegan studies because we did not identify any such studies in our literature search. We calculated the standardised mean difference (SMD) and its corresponding 95% confidence interval (CI). Studies reporting calcium measurements for different time periods of pregnancy were grouped according to gestational trimester. Additionally, we conducted tests for heterogeneity between studies by applying I^2 and performed calculation of sample heterogeneity using H^2; quantification of between study variability is based on Tau^2 statistics. Statistical performance is based on the summary results from the random effects model.[23] We also tested for publication bias using the funnel plot method as well as Egger's regression test[24] and Begg's rank correlation test.[25] Moreover, we performed sensitivity analysis as well as outlier and influence diagnostics.[26]

For all statistical analyses, we used version 4.0.3 of the R packages 'metafor',[27] 'robumenta',[28] 'dyplr'[29] and 'MAd'.[30]

RESULTS

We obtained 93 articles through PubMed and manual searching after removing duplicates. Screening of titles and abstracts resulted in 54 full-text articles considered eligible. Of these, we excluded 44 articles (for details see Figure 1: PRISMA Flow Chart and Supporting Information: Table S1). The remaining 10 studies reported daily intake of calcium or serum calcium concentration of pregnant women following a vegetarian diet and were examined for qualitative analysis. Six of those 10 studies were considered for quantitative meta-analysis, of which one study presented data from a previous investigation.[32] Those data[32] were regarded as a separate investigation, resulting in a total of seven studies for quantitative analysis.

Characteristics of included studies

The studies are various in geographic origin: two are from North America,[21,33] three are from Europe (United Kingdom and Germany),[22,32,34] and five are from Asia (India and China).[20,35–38] Furthermore, dietary assessment based on subjective estimates by means of visual aid were either food records, recalls for several days, 24 h-recalls or undefined methods.[21,22,32,36] Some studies reported calcium measurements separated for several pregnancy periods which we pooled by gestational trimester,[22,34] while other studies had either restricted to one group of pregnant women that were approximately at similar gestational ages or summarised their results across several pregnancy periods. All calcium measurements from the remaining seven studies were from dietary intake only. One study that

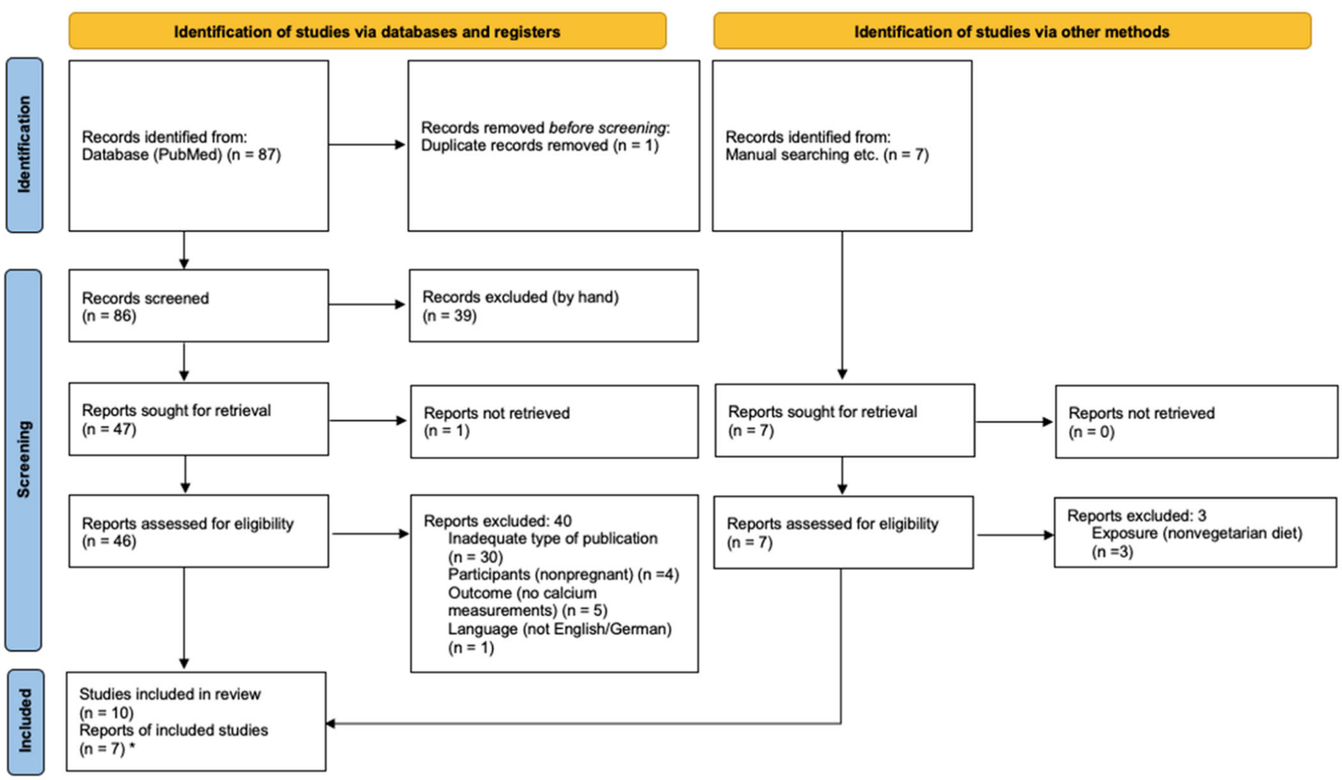

FIGURE 1 Flow diagram of study selection for the meta-analysis (Presentation according to Page, McKenzie, et al., 2021).[31]

also included supplements in its records we only considered calcium measurements excluding supplements for our analysis.[21] Seven studies were prospective cohort studies and three studies used a cross-sectional design. Two studies did not have an omnivorous comparison group,[20,35] one study did not report the SD of mean calcium intake,[33] and another study did not show the number of participants in each dietary group.[38] Therefore, those four studies[20,33,35,38] were not included in our quantitative analysis. Table 1 shows the main characteristics of the studies included.

Calcium intake in vegetarian and nonvegetarian pregnant women

Main analysis: The analysis of daily dietary calcium intake included four studies, comprising 752 vegetarian and 622 nonvegetarian pregnant women.[21,22,32,36] The mean calcium intake in vegetarian pregnant women was 1081.78 mg/d and it was 1014.99 mg/d in nonvegetarian controls. The difference in daily mean calcium intake between the two dietary groups was significant (SMD: 0.25; 95% CI: 0.14, 0.36).

Subanalyses: We conducted subanalyses according to study design (Figure 2). In cohort studies, we found a pooled mean calcium intake of 1246.43 mg/d in vegetarians, which was higher than the calcium intake of 1213.00 mg/d in nonvegetarians (SMD: 0.19; 95% CI: −0.04, 0.4). In cross-sectional studies, calcium intake in vegetarians (587.85 mg/d) was also higher than in nonvegetarians (420.97 mg/d; SMD: 0.32; 95% CI: 0.16, 0.48). The differences between study designs were not significant.

We next performed subanalyses by study geographic region (Figure 3). In studies from Asia, calcium intake was 587.85 mg/d in vegetarians, which was higher than calcium intake of 420.97 mg/d in nonvegetarians (SMD: 0.32; 95% CI: 0.16, 0.48). Likewise, in studies from Europe, calcium intake was 1218.14 mg/d in vegetarians and it was 1129.00 mg/d in nonvegetarians (SMD: 0.21; 95% CI: −0.06, 0.37). By comparison, a study from North America reported calcium intake of 1303.00 mg/d in vegetarians and 1381.00 mg/d in nonvegetarians without a significant difference (SMD: −0.13; 95% CI: −0.68, 0.42). With the exception of that North American study, higher calcium values in vegetarian than nonvegetarian women were consistent across geographic regions.

The assessment of heterogeneity performed within the random effects model between studies on calcium intake revealed no incidence for major variations between the included studies. The results yielded an I^2 of 0.01% (depicting total heterogeneity), a H^2 of 1.00 (representing sampling variability) and a Tau^2 of 0.00 (estimating the amount of heterogeneity). Based on a small number of studies, the funnel plots and Begg's mixed-effects meta-regression and Begg's rank test indicated no publication bias (Supporting Information: Appendix S4).

Absolute mean calcium intake from pregnant participants in comparison to calcium intake recommendations by respective regions

As an additional endpoint, we examined calcium intakes across studies to evaluate the adequacy of dietary calcium intake. Studies from the United Kingdom,[32] the United States[21] and Germany[22] met the recommendations for daily calcium intake in both dietary groups, while pregnant women from the study conducted in India[36] showed inadequate calcium supply according to regional recommendations. Supporting Information: Table S3 summarises absolute daily mean calcium intakes for dietary groups of pregnant women in juxtaposition to recommended calcium supplies during pregnancy by different nutritional institutions in different geographic regions.

Serum calcium concentrations in vegetarian and nonvegetarian pregnant women

Based on three studies, serum calcium levels in vegetarians (2.22 mmol/L) did not differ from those in nonvegetarians (2.24 mmol/L; SMD: – 0.15; 95% CI: −0.42, 0.11).

Additional subanalyses showed that the relation between diet and serum calcium levels was not modified by period of gestation or study geographic region (Supporting Information: Appendices S5 and S6).

Heterogeneity and variability between studies regarding serum calcium concentrations was very low ($I^2 = 0.00\%$; $H^2 = 1.00$; $Tau^2 = 0.00$). Based on the funnel plot method, Egger's mixed-effects meta-regression and Begg's rank test, we found no evidence for publication bias (Supporting Information: Appendix S7).

DISCUSSION

Main findings

The results of our meta-analysis showed a higher calcium intake in vegetarian pregnant women than in nonvegetarian pregnant women. The difference in dietary calcium intake between vegetarian and nonvegetarian pregnant women did not vary according to study design or study geographic region. We also found that both vegetarian and nonvegetarian pregnant women showed higher calcium intakes in Europe and North America than in Asia. Supporting Information: Table S2 summarises all statistical analyses.

In general, most participants of studies that were either considered for meta-analysis or qualitative analysis met the recommendations for calcium intake of their geographic region. It is noticeable that pregnant women who did not reach the recommendations were from Asian regions. Studies from India[20,33,35,36] reported that calcium intake recommendations of participating women were not met,

TABLE 1 Main characteristics of studies included for quantitative analysis.

Author (year)	Country, region	Study design	Pregnants/ lactating	Diet of participants	Dietary assessment	Definition of vegetarian diet	Gestational age	Calcium measurements	Calcium values (M ± SD)
Abraham (1985)	UK, Harrow	Prospective cohort	$P = 630$	$V = 405$ $NV = 225$	7-day-recall	LOV	NA	$I = 630$	$V = 1243.28 \pm 399.41$ mg/d $NV = 1165.00 \pm 375.00$ mg/d
Abraham (1985)[a]	UK, Harrow	Prospective cohort	$P = 64$	$V = 41$ $NV = 23$	7-day-recall	LOV	2. trimester (28 weeks)	$S = 64$	$V = 2.19 \pm 0.11$ mmol/L $NV = 2.20 \pm 0.11$ mmol/L
Bellows (2020)	India, Uttar Pradesh	Cross-sectional	$P = 627$	$V = 291$ $NV = 336$	Single multi-pass 24 h recall	LV	2–3. trimester	$I = 627$	$V = 587.85 \pm 596.64$ mg/d $NV = 420.97 \pm 451.16$ mg/d
Dent (1975)	UK, London	Prospective cohort	$P = 39$	$V = 23$ $NV = 16$	NA	NA	1. trimester (10–26 weeks) 2. trimester (28–32 weeks) 3. trimester (33–40 weeks)	$S = 39$	1. tri $V = 2.37 \pm 0.192$ mmol/L $NV = 2.36 \pm 0.16$ mmol/L 2. tri $V = 2.34 \pm 0.192$ mmol/L $NV = 2.34 \pm 0.16$ mmol/L 3. tri $V = 2.29 \pm 0.192$ mmol/L $NV = 2.39 \pm 0.16$ mmol/L
Finley (1983)	USA, California	Prospective cohort	$L = 60$	$V = 29$ $NV = 23$ $SV = 8$	24 h-recall, 2-day-record	LOV	NA	$I = 60$	$V = 1303.00 \pm 611.00$ mg/d $NV = 1381.00 \pm 571.00$ mg/d
Koebnick (2005)	Germany, Giessen	Prospective cohort	$P = 108$	$V = 27$ $NV = 38$ $SV = 43$	Estimated 4-day food record	LOV	1. trimester (9–12 weeks) 2. trimester (20–22 weeks) 3. trimester (36–38 weeks)	$I = 65$ (NA tri) $S = 65$ (1.–3. tri)	(S) 1. tri $V = 2.31 \pm 0.16$ $NV = 2.31 \pm 0.12$ mmol/L (S) 2. tri $V = 2.22 \pm 0.10$ mmol/L $NV = 2.26 \pm 0.12$ mmol/L (S) 3. tri $V = 2.23 \pm 0.15$ mmol/L $NV = 2.26 \pm 0.12$ mmol/L (I) $V = 1193.00 \pm 327.36$ mg/d $NV = 1093.00 \pm 271.20$ mg/d
Ward (1988)	India, Gujerat	Prospective cohort	$P = 62$	$V = 49$ $NV = 13$	7-day-recall	NA	2. trimester (28 weeks)	$S = 62$	$V = 2.10 \pm 0.21$ mmol/L $NV = 2.12 \pm 0.11$ mmol/L

Abbreviations: I, calcium intake; NA, not available; NV, nonvegetarian; V, vegetarian; LOV, lacto-ovo-vegetarian; LV, lacto-vegetarian; S, serum calcium concentration; tri, trimester.

[a]Data extracted from Ward et al.[37]

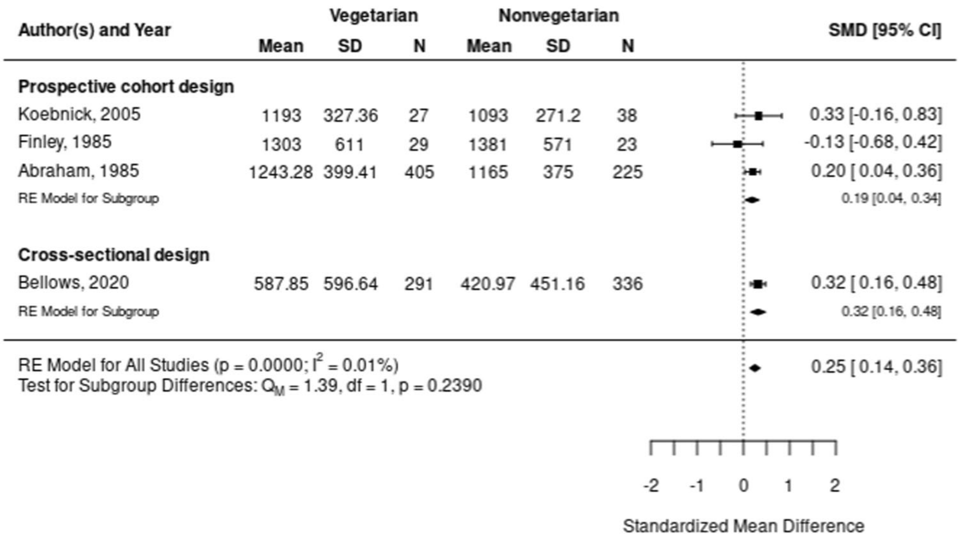

FIGURE 2 Forest plot of SMD in calcium intake (mg/d) between vegetarian and nonvegetarian participants according to study design. SMD, standardised mean differences.

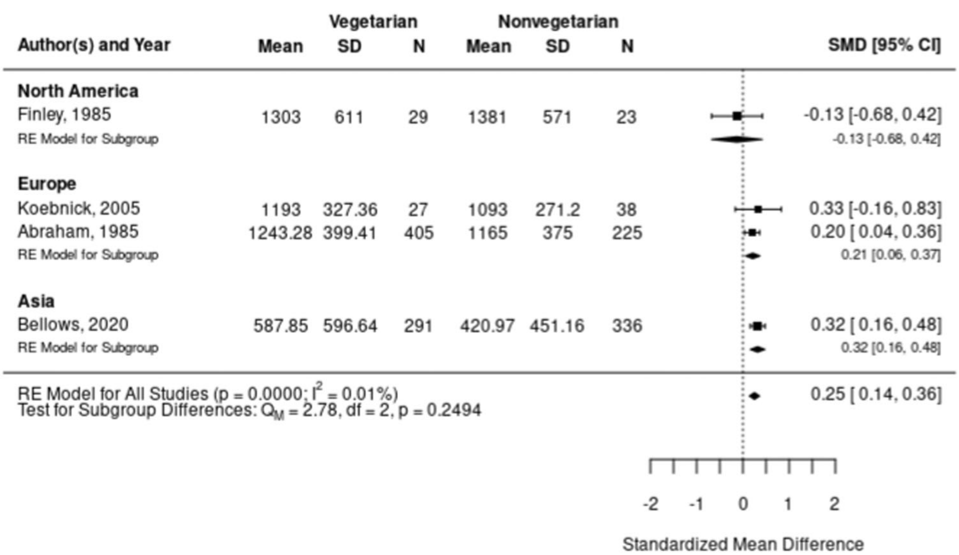

FIGURE 3 Forest plot of SMD in calcium intake (mg/d) between vegetarian and nonvegetarian participants according to geographic region. SMD, standardised mean differences.

regardless of dietary affiliation, while in contrast, a study from China stated that daily calcium supply was higher in vegetarians than omnivores during pregnancy.[38]

Calcium bioavailability

General calcium recommendations are made against the background of a 30% calcium absorption from food. When selecting sources of dietary calcium, both the abundance of calcium and bioavailability must be considered. Phytates and oxalates derived in many legumes and vegetables as well as fibres are limiting intestinal calcium absorption. Due to the fact that vegetarians relatively consume more plant foods and the bioavailability of calcium is reduced compared to nonvegetarians, people practicing vegetarianism should increase their calcium supply by about 20%.[7,12,14,39,40] Low oxalate plants therefore display a better source of plant-derived calcium than high oxalate plant foods because of higher absorption effectivity.[40] Another source of dairy-free calcium intake besides the consumption of beverages or foods fortified with calcium salts is calcium-rich mineral water. Bioavailability and concentration of calcium also is affected by several factors like water pH and concentration of anions.[41]

Calcium physiology and metabolism

Calcium is a mineral that has crucial functions in bone structure, muscle contractions, intracellular signalling, membrane potentials and neuronal activity. While most of the calcium is stored in the skeleton, only a very small part is relevant as free mobilised calcium in the serum, which is therefore kept constant in a narrow range. Calcium metabolism is controlled by a close interaction between calciotropic hormones (parathyroid hormone, calcitonin and calcitriol) and organs (small intestine, kidney and skeleton).[12,20,42,43] Calciotropic hormones limit wide fluctuations in serum calcium levels, especially in terms of free ionised calcium, which has major relevance for physiological processes.[12,42,44] In enterocytes of the upper small intestine calcium is absorbed both actively transcellularly and passively paracellularly. Active transcellular calcium absorption lies under the stimulating influence of calcitriol that upregulates the expression of apical and basolateral calcium transporters and most importantly calbindin, an intracellular calcium-binding protein.[43]

Adaptation of calcium homoeostasis during pregnancy

Increased demands of dietary calcium during pregnancy goes along with physiological changes in calcium homoeostasis within the process of maternofetal calcium transfer and the body's preparation for lactation period after delivery.[12,42] The main mechanism to adapt to the enhanced calcium requirement is an almost doubled intestinal calcium absorption already from a gestational age of 12 weeks driven by calcitonin and further factors. This should ensure sufficient maternal calcium stores even before maximal foetal calcium requirement in the last trimester, which at the same time serves to protect the maternal skeleton. Pregnant women who have chronically inadequate calcium intake (below 500 mg/d) therefore tend to have enhanced bone demineralisation.[12,42]

Total serum calcium levels decrease during pregnancy as a consequence of gestational hemodilution, leading to lower levels of albumin-bound calcium which has no physiological relevance as the active form of free ionised calcium remains constant. As dietary calcium intake is not correlated with serum calcium levels, it is not surprising that our meta-analysis showed that serum calcium levels are similar between vegetarian and nonvegetarian pregnant women.[20,45]

Associations of low calcium intake during pregnancy with maternal and foetal outcomes

Low daily calcium intakes during pregnancy as reported in studies from Asian regions are associated with several adverse maternal and foetal outcomes. Adverse effects on foetal health are prematurity, reduced intrauterine growth resulting in lower birthweight, and most importantly, poor bone mineralisation. Adverse maternal outcomes related to poor calcium supply during pregnancy include hypertensive disorders such as pre-eclampsia.[8–13] The World Health Organization (WHO) recommends calcium supplementation of 1500–2000 mg/d for the prevention of pre-eclampsia, which is still one of the main causes for maternal death, especially in low- and middle-income countries (LMICs).[9,11,12,46,47]

Global disparities in calcium intake during pregnancy

Malnutrition, particularly micronutrient deficiency during pregnancy, is a common issue in LMICs.[36] Three of the four Asian studies were performed in India, where low socioeconomic status, low levels of maternal education and lack of nutrition awareness may lead to poor nutrition status.[20,35,36] The other Asian study was conducted in Shaanxi, China.[38] Calcium intake was described as insufficient in all four Asian studies.[20,35,36,38] A meta-analysis evaluating global inequities in calcium consumption during pregnancy showed results consistent with our findings.[9] Calcium intake during pregnancy in high-income countries (HICs) (948.30 mg/d) versus LMICs (647.60 mg/d) revealed a significant mean difference of approximately 300 mg/d of calcium, confirming that a nutritional gap still exists between HICs and LMICs ($p < 0.00001$). Approaches for raising dietary calcium intakes in pregnant women range from interventions targeting women's nutritional behaviours to supplementation and food fortification.[9] A systematic review on pregnancy outcomes in vegan and vegetarian pregnant women concluded that vegetarian diets have distinct correlates of poverty and prosperity across geographic regions. While vegetarianism is linked to higher education and income in affluent countries, it co-exists with limited availability of food or religious beliefs and traditions (Hinduism) in countries with lower income.[10] The composition of vegetarian diets in developed and developing regions also differs. 'Western' vegetarian diets are often richer in vitamins, fibre and trace elements compared to mixed diets, while vegetarian diets in poorer regions are characterised by a sizeable proportion of starchy staple foods and hence, posing greater risk for nutritional deficiencies.[48]

Positions on vegetarianism during pregnancy in terms of calcium intake

Most studies reported adequate calcium intakes in vegetarians and omnivores, with calcium intakes in vegetarian pregnant women exceeding those of their nonvegetarian counterparts, except for studies in LMICs. Thus, in terms of calcium supply, we support the position of both the German Society for Nutrition (DGE) and the American Academy of Nutrition and Dietetics (AND) on vegetarian diet during pregnancy. Both state-balanced vegetarian diets to be nutritionally adequate when attention is paid to sufficient micronutrient intake.[3,5] Because no vegan pregnancy was reported in any study considered in our meta-analysis, we cannot draw conclusions about calcium intake for vegan diets during pregnancy. Pregnant women are at greater risk for nutritional deficiencies, especially when following a plant-based diet. The DGE does not recommend a strictly vegan diet while pregnant because such a diet lacks numerous foods dense in micronutrients. However, the DGE deems lacto-ovo-vegetarian diets adequate in micronutrients when those diets are properly balanced and planned. International positions on meatless diets during pregnancy differ in their recommendations and are sometimes contradictory because of varying food circumstances such as fortification in certain geographic regions. For example, enrichment of grocery products with micronutrients is mandatory in the United States, which results in an overall lower risk of deficiencies in micronutrients in the general population, and even a purely vegan diet is considered adequate for pregnant women.[49]

Strengths and limitations

Potential shortcomings of our analysis include the small number of studies and participants, limiting the precision of our data. This is also the reason why we could not adjust for potential confounders in our meta-analysis. Also, some studies assessed dietary intake several decades ago, where eating behaviours differed from today especially regarding vegan and/or vegetarian diets and an increased availability of plant based dairy and meat alternatives. In addition, inaccuracies may have occurred during the collection of data on calcium intake due to subjective dietary assessment based on self-report. Food frequency questionnaires although representing the most practical method in large prospective studies are limited in explanatory power of adequately evaluating diet composition. Furthermore, calcium intake was recorded across multiple trimesters but the reports were not presented separately by gestational age, making it difficult to summarise the data according to pregnancy trimester.

Nutritional studies among pregnant women are sparse and they sometimes report contradictory results, especially in terms of vegetarian diets.[10] Despite these limitations, the major strength of our analysis is that, to the best of our knowledge, the current study is the first meta-analysis on calcium intake in pregnant women following vegetarian diets. Also, our paper references current nutritional advice for pregnant women, some of which is contradictory.

CONCLUSION

There is an increasing demand for data regarding the risks and benefits of vegetarian nutrition during pregnancy, a vulnerable time period because diet has a considerable impact on both maternal and foetal health. Our meta-analysis showed a significantly increased calcium intake in vegetarian pregnant women compared to those adhering to nonvegetarian diets. Because of the limited number of available studies in this area, we advocate further implementation of large-scale observational studies assessing micronutrient status and calcium intake in vegetarian and vegan diets during pregnancy.

AUTHOR CONTRIBUTIONS

Carmen Jochem, Franziska Bickelmann and Marina Kasper contributed to the idea and carried out literature research, data extraction and statistical analysis. Michael Leitzmann and Carmen Jochem supervised the development of this paper. All authors critically revised the content and agreed to the final version of this manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

The authors do not provide ethical statements or informed consent because this meta-analysis and systematic review does not include studies conducted in human or animal subjects for this work. Secondary data used for the quantitative and qualitative analysis were available for public insight.

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REFERENCES

1. The Vegan Society. *Worldwide Growth of Veganism*. The Vegan Society. https://www.vegansociety.com/news/media/statistics/worldwide
2. ProVeg EV. Anzahl der vegan und vegetarisch lebenden Menschen in Deutschland: ProVeg e.V; 2016. Accessed December 12, 2016. https://proveg.com/de/ernaehrung/anzahl-vegan-vegetarischer-menschen/
3. Richter M, Boeing H, Grünewald-Funk D, et al. Vegan diet. Position of the German Nutrition Society (DGE). *Ernaehrungsumschau*. 2016;63:92-102.
4. Snetselaar LG, de Jesus JM, DeSilva DM, Stoody EE. Dietary Guidelines for Americans, 2020–2025. *Nutr Today*. 2021;56(6):287-295.
5. Melina V, Craig W, Levin S. Position of the academy of nutrition and dietetics: vegetarian diets. *J Acad Nutr Diet*. 2016;116(12):1970-1980.
6. Koletzko B, Cremer M, Flothkötter M, et al. Diet and lifestyle before and during pregnancy—practical recommendations of the Germany-wide healthy start—young family network. *Geburtshilfe Frauenheilkd*. 2018;78(12):1262-1282.

7. Penney DS, Miller KG. Nutritional counseling for vegetarians during pregnancy and lactation. *J Midwifery Womens Health*. 2008;53(1):37-44.
8. Mannion CA, Lindop RJ. Vitamin/mineral supplements and calcium-based antacids increase maternal calcium intake. *J Am Coll Nutr*. 2009;28(4):362-368.
9. Cormick G, Betrán A, Romero I, et al. Global inequities in dietary calcium intake during pregnancy: a systematic review and meta-analysis. *BJOG*. 2019;126(4):444-456.
10. Piccoli G, Clari R, Vigotti F, et al. Vegan-vegetarian diets in pregnancy: danger or panacea? A systematic narrative review. *BJOG*. 2015;122(5):623-633.
11. Jouanne M, Oddoux S, Noël A, Voisin-Chiret AS. Nutrient requirements during pregnancy and lactation. *Nutrients*. 2021;13(2):692.
12. Kumar A, Kaur S. Calcium: a nutrient in pregnancy. *J Obstet Gynecol India*. 2017;67(5):313-318.
13. Willemse JPMM, Meertens LJE, Scheepers HCJ, et al. Calcium intake from diet and supplement use during early pregnancy: the expect study I. *Eur J Nutr*. 2020;59(1):167-174.
14. Sebastiani G, Herranz Barbero A, Borrás-Novell C, et al. The effects of vegetarian and vegan diet during pregnancy on the health of mothers and offspring. *Nutrients*. 2019;11(3):557.
15. Li T, Li Y, Wu S. Comparison of human bone mineral densities in subjects on plant-based and omnivorous diets: a systematic review and meta-analysis. *Archiv Osteoporosis*. 2021;16(1):95.
16. Bickelmann FV, Leitzmann MF, Keller M, Baurecht H, Jochem C. Calcium intake in vegan and vegetarian diets: a systematic review and meta-analysis. *Crit Rev Food Sci Nutr*. 2022;62:1-19.
17. Moher D, Liberati A, Tetzlaff J, Altman DG, Group P. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *Open Med*. 2009;3(3):e123-e130.
18. Page MJ, Moher D, Bossuyt PM, et al. PRISMA 2020 explanation and elaboration: updated guidance and exemplars for reporting systematic reviews. *BMJ*. 2021;372:n160.
19. McGrath S, Zhao X, Steele R, et al. Estimating the sample mean and standard deviation from commonly reported quantiles in meta-analysis. *Stat Methods Med Res*. 2020;29:2520-2537.
20. Kumar A, Meena M, Gyaneshwori Devi S, Gupta RK, Batra S. RETRACTED ARTICLE: calcium in midpregnancy. *Arch Gynecol Obstet*. 2009;279(3):315-319.
21. Finley DA, Dewey KG, Lönnerdal B, Grivetti LE. Food choices of vegetarians and nonvegetarians during pregnancy and lactation. *J Am Diet Assoc*. 1985;85(6):678-685.
22. Koebnick C, Leitzmann R, García AL, et al. Long-term effect of a plant-based diet on magnesium status during pregnancy. *Eur J Clin Nutr*. 2005;59(2):219-225.
23. Higgins JPT, Thompson SG. Quantifying heterogeneity in a meta-analysis. *Stat Med*. 2002;21(11):1539-1558.
24. Egger M, Smith GD, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. *BMJ*. 1997;315(7109):629-634.
25. Begg CB, Mazumdar M. Operating characteristics of a rank correlation test for publication bias. *Biometrics*. 1994;50(4):1088-1101.
26. Viechtbauer W, Cheung MWL. Outlier and influence diagnostics for meta-analysis. *Res Synth Methods*. 2010;1(2):112-125.
27. Viechtbauer W. Conducting meta-analyses in R with the metafor package. *J Stat Softw*. 2010;36(3):1-48.
28. Fisher ZTE. Robumeta: an R-package for robust variance estimation in meta-analysis. *arXiv*. 2015.
29. Wickham HFR, Henry L, Müller K. dplyr: a grammar of data manipulation. *R package version*. 2015;04:3.
30. Cooper HM, Hedges LV, Valentine JC. *The Handbook of Research Synthesis and Meta-Analysis*. 2nd ed. Russell Sage Foundation; 2009:615.
31. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*. 2021;n71. doi:10.1136/bmj.n71
32. Abraham R, Campbell-Brown M, Haines AP, North WR, Hainsworth V, McFadyen IR. Diet during pregnancy in an Asian community in Britain—energy, protein, zinc, copper, fibre and calcium. *Hum Nutr Appl Nutr*. 1985;39(1):23-35.
33. Hardinge MG, Stare FJ. Nutrition studies of vegetarians. 1. Nutritional, physical, and laboratory studies. *J Clin Nutr*. 1954;2(2):72-82.
34. Dent C. Plasma 25-hydroxyvitamin-D-levels during pregnancy in Caucasians and in vegetarian and nonvegetarian Asians. *Lancet*. 1975;306(7944):1057-1060.
35. Bhatia BD, Banerjee D, Agarwal DK, Agarwal KN. Dietary intakes of urban and rural pregnant, lactating and non-pregnant, non-lactating vegetarian women of Varanasi. *Indian J Med Res*. 1981;74:680-687.
36. Bellows AL, Kachwaha S, Ghosh S, et al. Nutrient adequacy is low among both self-declared lacto-vegetarian and nonvegetarian pregnant women in Uttar Pradesh. *Nutrients*. 2020;12(7):2126.
37. Ward RJ, Abraham R, McFadyen IR, et al. Assessment of trace metal intake and status in a Gujerati pregnant Asian population and their influence on the outcome of pregnancy. *BJOG*. 1988;95(7):676-682.
38. Yang J, Dang S, Cheng Y, et al. Dietary intakes and dietary patterns among pregnant women in Northwest China. *Public Health Nutr*. 2017;20(2):282-293.
39. Venti CA, Johnston CS. Modified food guide pyramid for lactovegetarians and vegans. *J Nutr*. 2002;132(5):1050-1054.
40. Weaver CM, Proulx WR, Heaney R. Choices for achieving adequate dietary calcium with a vegetarian diet. *Am J Clin Nutr*. 1999;70 (3 suppl):543S-548S.
41. Cotruva J, Bartram J. *Calcium and Magnesium in Drinking-Water*. World Health Organization; 2009.
42. Almaghamsi A, Almalki MH, Buhary BM. Hypocalcemia in pregnancy: a clinical review update. *Oman Med J*. 2018;33(6):453-462.
43. Pape H-C, Kurtz A, Silbernagl S. *Physiologie*. 8th ed. Thieme; 2018.
44. Pitkin RM, Gebhardt MP. Serum calcium concentrations in human pregnancy. *Am J Obstet Gynecol*. 1977;127(7):775-778.
45. Kumar A, Agarwal K, Devi SG, Gupta RK, Batra S. Hypocalcemia in pregnant women. *Biol Trace Elem Res*. 2010;136(1):26-32.
46. Hofmeyr GJ, Lawrie TA, Atallah Á, Torloni MR. Calcium supplementation during pregnancy for preventing hypertensive disorders and related problems. *Cochrane Database Syst Rev*. 2018;10:CD001059.
47. World Health Organization. *WHO Recommendation: Calcium Supplementation During Pregnancy for the Presentation of Pre-Eclampsia and Its Complications*. World Health Organization; 2018.
48. Sanders TAB. The nutritional adequacy of plant-based diets. *Proc Nutr Soc*. 1999;58(2):265-269.
49. Richter M. *Update to the Position of the German Nutrition Society on Vegan Diets in Population Groups with Special Nutritional Requirements*. German Nutrition Society; 2020:64-72.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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