Systematic Review

Vegetarian and Vegan Diets and the Risk of Hip Fracture in Adults: A Systematic Review and Meta-analysis

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Introduction: *Hip fracture is an important cause of hospitalization, with high morbidity and mortality. Evidence suggests that vegetarians and vegans have lower bone mineral density, and plant-based diets are gaining popularity. However, the impact of these diets on the occurrence of hip fracture risk remains unclear.*

Objective: *This systematic review aimed to assess the impact of vegetarian and vegan diets on the risk of hip fracture in adults.*

Methods: *We conducted a systematic review of studies comparing vegetarians and vegans with meat-eaters. We searched Medline, EMBASE, LILACS, CINAHL, Scopus, and Cochrane Central Register of Controlled Trials (CENTRAL). Two reviewers independently and in duplicate performed study selection, risk-of-bias assessment, and data extraction. Hazard ratios (HRs) with 95% CIs were calculated as an estimate of the effect of vegetarian and vegan diets. The quality of evidence was determined according to the Grading of Recommendations Assessment, Development, and Evaluation.*

Results: *Four cohort studies with 529 672 participants were included. Both vegetarian and vegan diets were associated with a higher risk of hip fracture after adjusting for confounders. Vegetarians had a 25% higher risk than meat-eaters (HR, 1.25; 95% CI, 1.11–1.39; 38 433 vegetarians; $I^2 = 0\%$; low certainty of evidence). Vegans had a 75% higher risk (HR, 1.75; 95% CI, 1.17–2.63; 5344 vegans; $I^2 = 64\%$; very low certainty of evidence).*

Conclusion: *These findings emphasize the importance of incorporating dietary patterns into strategies for promoting bone health, especially among individuals following plant-based diets. Healthcare providers should offer guidance to individuals adopting vegetarian or vegan diets to ensure adequate nutrient intake and support bone health.*

Systematic Review Registration: *PROSPERO no. CRD 42024592448.*

Key words: vegan diet, vegetarian diet, hip fracture, cohort study, aging.

INTRODUCTION

Population aging due to increased life expectancy is a global phenomenon. According to the World Health Organization, by 2050, 1.6 billion people will be aged 65 years or older, representing 17% of the global population.[1] As this demographic shift occurs, the incidence of hip fractures is expected to double by 2050.[2] Among

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elderly individuals, hip fractures rank as the sixth most common cause of hospitalization.[3]

Hip fractures substantially impact morbidity and mortality. The 1-year mortality rate following hip fracture surgery can reach up to 36%,[4] with cardiovascular, pulmonary, thrombotic, infectious, and hemorrhagic complications being the leading causes of death. Survivors often face considerable disability, with many experiencing increased dependency and requiring institutional care.[5,6]

Beyond the individual burden, hip fractures impose substantial costs on healthcare systems. These costs arise directly from treatment expenses and indirectly from complications, readmissions, and rehabilitation.[7] Consequently, identifying and addressing risk factors for hip fractures remains a public health priority.

Fracture risk is influenced by various factors, including bone disorders, medication use, physical inactivity, and hormonal changes.[8] Nutrition also plays a crucial role. Recently, emerging dietary patterns, such as vegetarian and vegan diets, have gained popularity due to health, environmental, ethical, and religious motivations.[5]

Previous studies indicate that bone mineral density (BMD) tends to be lower in vegetarians compared with nonvegetarians.[9] However, these studies often group vegetarians and vegans together and inadequately adjust for key variables such as calcium intake, vitamin D levels, and body mass index (BMI). Moreover, few studies systematically summarize the clinical impact of these diets on hip fracture risk. Therefore, this study aims to systematically review current evidence on the association between vegetarian and vegan diets and hip fracture incidence.

METHODS

This systematic review and meta-analysis has been reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[10] This study was registered in PROSPERO (International Prospective Register of Systematic Reviews, CRD 42024592448).

Eligibility Criteria

Cohort studies with adult patients with vegan and vegetarian diets and hip fractures were included in the review. Eligibility criteria were defined using the PECO (Population, Exposure, Comparison, Outcome) framework detailed in **Table 1**.

Table 1. PECO Criteria for Inclusion of Studies

Parameter	Criteria
P—Population	**Adult participants aged 18 y and older**
E—Exposure	Vegetarian and vegan diets were considered eligible. Vegetarians were defined as individuals who consumed eggs and/or dairy but avoided meat and fish. Vegans were defined as those who excluded all animal-derived foods, including meat, fish, eggs, and dairy.
C—Comparison	Control groups consisted of meat-eaters, including individuals who consumed red meat, processed meat, poultry, and fish.
O—Outcome	Occurrence of hip fracture.

Exclusion Criteria

Studies that did not focus exclusively on vegetarian or vegan diets, such as those using broader or alternative dietary classifications (eg, plant-based diets, fish-eaters, semi-vegetarians, or occasional meat-eaters), were excluded.

Search Strategy

A comprehensive search was conducted across PubMed, EMBASE (via Ovid), CINAHL (via EBSCO), Cochrane Central Register of Controlled Trials (CENTRAL), and Scopus, from inception to October 1, 2024. Search terms included "hip fracture," "vegetarian diet," "vegetarianism," "vegan diet," "veganism," and their respective synonyms, combined using Boolean operators "AND" and "OR." We applied no language or date restrictions. The complete search strategy is detailed in **Table S1**.

Study Selection

Two authors (R.S.B. and T.L.) independently screened titles and abstracts and then full texts. Disagreements were resolved through discussion with a third reviewer (D.E.). Rayyan software (USA) was used to manage the screening process.[11]

Data Extraction

R.S.B. and T.L. independently extracted data from the final included full texts. Discrepancies were resolved by discussion with D.E. When necessary, we contacted the corresponding authors to obtain missing information. For studies with multiple reports, we selected the most complete and recent version.

Risk of Bias

R.S.B. and T.L. independently assessed the risk of bias using the ROBINS-I tool (Risk Of Bias In Non-

randomized Studies—of Interventions). This tool is designed to assess the risk of bias in nonrandomized studies that evaluate the effects of interventions. It includes 7 domains organized to reflect the flow of a study from baseline to outcome (bias due to confounding, bias in selection of participants, bias in classification of interventions, bias due to deviation from intended interventions, bias due to missing data, bias in measurement of outcomes, and bias in selection of the reported result). Risk of bias was classified as low, moderate, serious, critical, or no information.[12] Disagreements were resolved through consensus with D.E.

Data Synthesis and Analysis

We conducted statistical analyses using Review Manager (RevMan) version 5.4.1. Significance was set at $P < .05$. Hazard ratios (HRs) and 95% CIs were extracted to estimate the effect of diet type on hip fracture risk, using meat-eaters as the reference group.

Multivariable-adjusted HRs were used in the meta-analysis, prioritizing models that accounted for key confounding variables such as age, sex, BMI, physical activity, and relevant dietary factors. This strategy aims to reduce the risk of confounding bias and improve the comparability of effect estimates across studies. The covariates included in each adjusted model are detailed in **Table S2**. We selected the most complete and similarly adjusted models available across studies to ensure consistency in the pooled estimates.

The HRs and their CIs were entered into RevMan, which automatically log-transformed the HRs and calculated the corresponding standard errors for meta-analysis. The weight assigned to each study was calculated using the inverse variance method, and a random-effects model was applied to account for between-study variability. Heterogeneity was assessed using Higgins inconsistency statistic (I^2). Substantial heterogeneity was defined as $I^2 > 50\%$ and a P value $< .10$ on the Cochran's Q test.[12]

Formal sensitivity analyses were not conducted due to the small number of eligible studies ($n = 4$), which limited the statistical power and feasibility of subgroup or leave-one-out analyses. Additionally, by including only similarly adjusted multivariable models, we minimized methodological heterogeneity, reducing the necessity for further sensitivity testing.

Quality of Evidence Assessment

Two reviewers (R.S.B. and T.L.) independently assessed the quality of evidence using GRADE (Grading of Recommendations Assessment, Development, and Evaluation).[13] Disagreements were resolved through discussion or consultation with a third reviewer (D.E.). This system assesses methodological limitations, inconsistency, imprecision, indirectness, and publication bias to categorize the quality of evidence as very low, low, moderate, or high. The summary of findings table (**Table S3**) was created using GRADEpro GDT software.

RESULTS

The search strategy resulted in 200 articles and 127 articles after duplicates were removed using EndNote software. Following the selection process, 6 articles were selected for full-text review. Of these, 4 cohort studies met the inclusion criteria and were included in both the systematic review and meta-analysis (**Figure 1**). Among the excluded studies, 121 failed to meet eligibility criteria, and 2 assessed dietary patterns that did not align with the definitions of vegetarian or vegan diets.

The included studies involved a total of 529 672 participants. **Table 2**[14–17] presents the distribution of participants by dietary pattern. The overall mean age was 55.5 years, calculated as a weighted average based on the sample size of each study. The majority were female ($n = 301\,658$; 57%). One study was conducted only with females,[14] and 3 studies with both genders.[15–17] The mean follow-up was 15.2 years. Even without a period limitation, the publications included were published between 2020 and 2024.

According to the studies, 5949 hip fracture cases were reported. One study assessed 6 site-specific fractures,[15] while the other studies only assessed hip fractures. All studies classified participants' dietary patterns using food-frequency questionnaires. In each cohort, vegetarians and vegans were compared with a reference group of meat-eaters.[14–17]

Given the importance of adjusting for confounders in the cohorts presented, the most appropriate way to summarize the results was by conducting a meta-analysis using the results of multivariate analyses adjusted for confounding factors that were similar across the studies, such as sex, age, dietary factors, physical activity, and lifestyle habits (**Table S2**).

Our meta-analysis showed that vegetarian and vegan diets were more susceptible to hip fractures. A vegetarian diet was associated with a 25% higher risk (HR, 1.25; 95% CI, 1.11–1.39; 4 studies; 38 433 vegetarian participants; $I^2 = 0\%$; **Figure 2**; low certainty of evidence) (**Table S3**). A vegan diet was associated with an even greater risk, showing a 75% increase (HR, 1.75; 95% CI, 1.17–2.63; 4 studies; 5344 vegan participants; I2 = 64%; **Figure 3**; very low certainty of evidence) (**Table S4**).

Risk-of-bias assessment was conducted using the Cochrane ROBINS-I tool (**Figure S1**). According to the assessment, all studies generally showed confounding

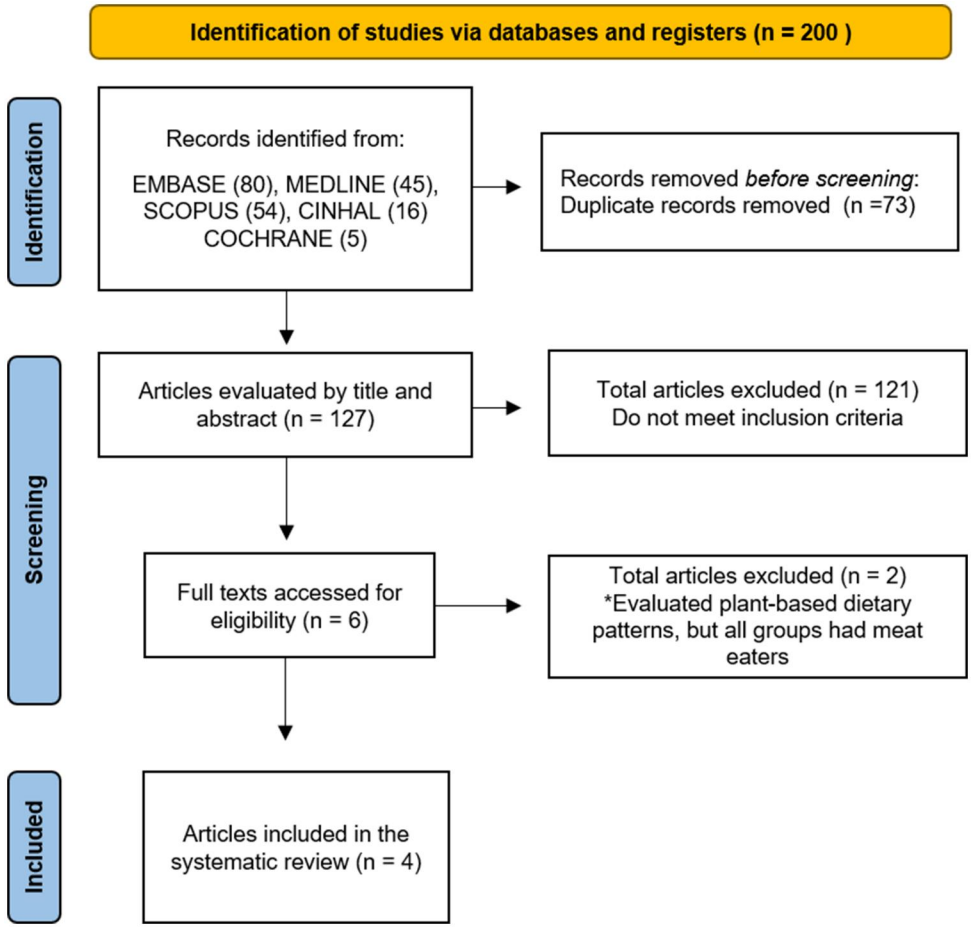

Figure 1. Flowchart of Study Selection

Table 2. Characteristics of Studies That Reported the Relationship Between Vegetarian or Vegan Diets in Relation to Hip Fracture

	Country	Participants, n	Mean age, y	Gender (female, n), n	Meat-eaters, n (%)	Vegetarian, n (%)	Vegan, n (%)	Hip fracture, n	Follow-up, y
Tong et al (2020)[15]	United Kingdom	54 898	45.8	42 382	29 380 (49.05)	15 499 (28.23)	1982 (3.61)	945	17.6
Thorpe et al (2021)[16]	United States, Canada	34 542	63.2	18 732	14 656 (42.42)	12 008 (34.76)	2832 (8.19)	679	8.4
Webster et al (2022)[14]	United Kingdom	26 318	52.1	26 318	12 221 (46.43)	3688 (14.01)	130 (0.49)	822	22.3
Webster et al (2023)[17]	United Kingdom	413 914	56.3	214 226	258 765 (62.51)	7238 (1.74)	400 (0.09)	3503	12.5
Total		529 672	55.5	301 658	315 022	38 433	5344	5949	

bias due to the intrinsic characteristics of the cohort participants. One particularly prominent variable discussed in the original articles was age. Overall, vegetarian and vegan groups were younger, which could reduce the risk of fractures solely due to age, complicating the direct evaluation of diet. However, all studies had statistically controlled for confounders in their analyses (**Table S2**).

The most critical point regarding the risk of bias was in domain 4 (bias due to deviations from intended interventions), related to the receipt of the assigned intervention. This occurred due to significant dietary group changes during follow-up,[15] or because the lack of dietary pattern reassessment made it impossible to estimate the percentage of group changes.[14,16] Only 1 of the studies reported little evidence of diet group changes over time,[17] performing adequately in this domain.

The certainty of the evidence was low for the findings for vegetarians due to serious risk of bias and imprecision, and very low for the findings for vegans

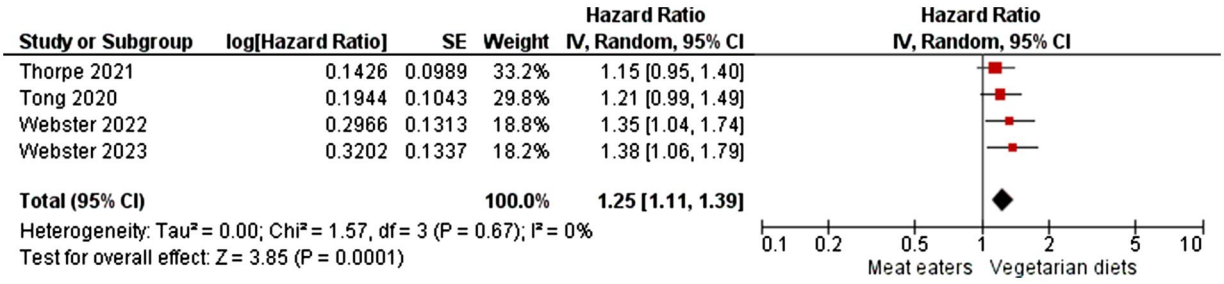

Figure 2. Forest Plot Showing the Association Between a Vegetarian Diet and Hip Fracture Risk

Abbreviation: IV, inverse variance.

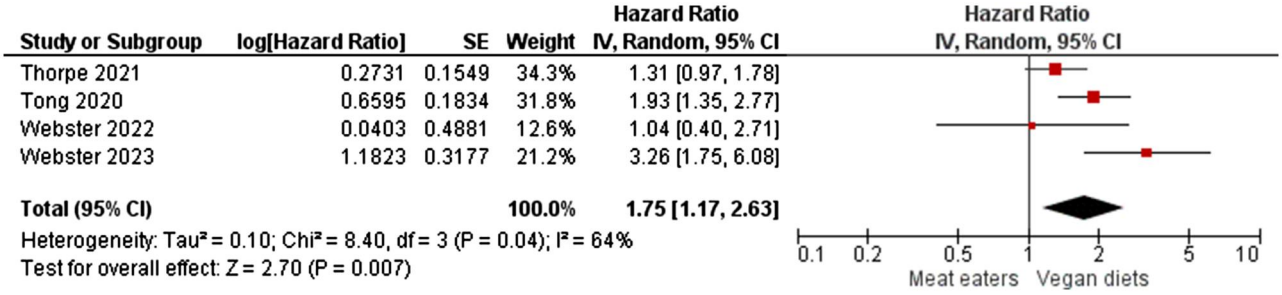

Figure 3. Forest Plot Showing the Association Between a Vegan Diet and Hip Fracture Risk

Abbreviation: IV, inverse variance.

due to serious risk of bias, inconsistency, and imprecision, despite the greater impact on risk of fracture in vegans. **Tables S3 and S4** summarize the GRADE assessments.

DISCUSSION

With the increasing adoption of vegetarian and vegan diets, evaluating the health outcomes associated with these dietary patterns has become essential.[5,18,19] Beyond their environmental benefits, evidence suggests that vegetarian and vegan diets may offer protective effects against coronary heart disease and type 2 diabetes,[20–22] and are also associated with a reduced risk of certain cancers, including postmenopausal breast, prostate, and colorectal cancers.[23,24]

However, despite these potential benefits, concerns have emerged regarding the impact of plant-based diets on bone health. Several studies have reported an association between vegetarian and vegan diets and poorer bone health outcomes.[14–17,25] Specifically, reduced BMD and increased risk of fractures have been associated with characteristically low dietary intakes of calcium, vitamin D, zinc, n–3 polyunsaturated fatty acids (PUFAs), and protein, all dietary nutrients that have been shown to be important and positively associated with BMD.[26–28]

Our findings align with previous evidence, indicating that both vegetarian and vegan diets are associated with an increased risk of hip fracture. In absolute terms, vegetarian diets result in approximately 2 additional hip fractures per 1000 individuals (ranging from 1 to 4 more), while vegan diets lead to approximately 8 additional cases per 1000 individuals (ranging from 2 to 17 more). This concern is particularly pronounced among vegans, as they exclude dairy products, a primary dietary source of calcium. Additionally, the higher calcium content, bioavailability, and absorption from animal-based foods, compared with plant-based sources, may result in a compromised total calcium balance in vegetarians and vegans relative to meat-eaters.[28,29]

Vitamin D has a key role in calcium absorption from the gut and is also important in muscle performance, balance, and the risk of falling.[30] Although the primary source of vitamin D is through skin synthesis,[31] most studies indicate that vegetarians and vegans tend to have lower dietary intake of vitamin D. This is largely because the richest sources of vitamin D are fatty fish and fortified dairy products, while vitamin D_2 from plant sources may be less bioavailable than vitamin D_3 found in animal-based foods.[28,32]

Recently, Li et al[9] performed a systematic review and meta-analysis to compare the effects of plant-based and omnivorous diets on BMD (g/cm^2). They found lower BMD at the lumbar spine (mean difference [MD],

−0.04; 95% CI, −0.05 to −0.02), femoral neck (MD, −0.04; 95% CI, −0.06 to −0.02), and whole body (MD, −0.03; 95% CI, −0.06 to −0.01) in vegans and vegetarians when compared with omnivores.

Likewise, Iguacel et al[33] performed a systematic review and meta-analysis to study the effect of vegetarian and vegan diets compared with omnivorous diets on BMD and on fracture rates. The findings on BMD at the lumbar spine and femoral neck were similar to those of Li et al,[9] but they also found a significantly higher fracture risk in vegans (relative risk [RR], 1.44; 95% CI, 1.05–1.98; $P < .001$), but not in vegetarians, in comparison with omnivores. However, only crude ratios were used in this review.

Men typically exhibit higher BMD and greater cortical bone mass compared with women,[34] factors that contribute to a lower risk of fractures in men. Additionally, the more rapid and pronounced loss of estrogen experienced by women during menopause has a more substantial impact on bone health compared with the gradual decline in androgens seen in men.[35]

Age is also a critical risk factor for bone loss, with approximately 50% of White women developing osteopenia or osteoporosis by the age of 60.[36] Given that peak bone mass is generally achieved between 20 and 30 years of age, nutritional and hormonal factors during childhood and adolescence play a crucial role in determining bone health later in life. These factors, combined with age, significantly influence the risk of hip fractures, particularly in older adults.[37]

With regard to body composition, vegetarians and vegans typically exhibit lower body weight and lean body mass (LBM) compared with omnivores. This reduction in LBM is associated with decreased BMD and an elevated risk of fractures, as the mechanical load exerted on bones by muscle activity plays a critical role in promoting bone mass accrual and maintaining skeletal strength.[28]

Many studies found that vegetarians and vegans had lower BMI than meat-eaters.[14,15,17,38] The relationship between BMI and bone health is complex and must be carefully evaluated in the context of fracture risk and BMD. Although women with low BMI are at increased risk of osteoporosis and an increase in body weight causes an increase in BMD both for a mechanical effect and for the greater amount of estrogens present in the adipose tissue, patients with obesity also have a greater risk of fracture, especially atypical distribution fractures, due to metabolic factors and increased risk of falls.[39,40]

Considering that several genetic and lifestyle factors influence BMD,[37] which may introduce potential confounding bias in the analyzed cohorts, we opted to use adjusted HRs in our meta-analysis. This approach ensured consistency and comparability across the 4 included studies, providing the most comprehensive and similarly adjusted model (**Table S2**).

Tong et al[15] performed a cohort study using European Investigation into Cancer and Nutrition (EPIC)–Oxford study[27] data with more than 55 000 individuals, and found that the risk of hip fracture was higher in the vegan diet group (HR, 1.94; 95% CI, 1.35–2.77) compared with meat-eaters after adjustments.

Thorpe et al[16] performed a study using data from the Adventist Health Study 2 cohort[41] to evaluate the influence of dietary patterns on hip fracture risk and whether this association is modified by concomitant calcium and vitamin D supplementation. They found that, in the age- and multivariable-adjusted HR model, vegan women had a higher risk of hip fracture (HR, 1.55; 95% CI, 1.06–2.26). This association was not observed in the primary analysis that included the entire population. Concerning calcium and vitamin D supplementation, vegan women who did not take any supplements had nearly 3 times the risk of hip fracture compared with nonvegetarian women (HR, 2.99; 95% CI, 1.54–5.82). In contrast, among women who used the combined supplements, no significant increase in hip fracture risk was observed. Similarly, Webster et al,[14] after multivariable adjustments, found in a prospective cohort study that vegetarian women had a higher risk of hip fracture (HR, 1.35; 95% CI, 1.04–1.74) compared with women who consume meat.

In a more recent and larger study involving over 400 000 individuals, Webster et al[17] assessed the risk of hip fractures among vegetarians and vegans. After multivariable adjustments, they reported that both vegetarians (HR, 1.38; 95% CI, 1.06–1.79) and vegans (HR, 3.26; 95% CI, 1.75–6.08) had a higher risk of hip fractures compared with meat-eaters. Our findings suggest a potential increase in hip fracture risk among individuals on vegetarian or vegan diets, even after controlling for key confounding factors.

This meta-analysis has several strengths. By including hip fracture rates adjusted for multiple variables, we were able to provide a more accurate estimation of the overall effect size of vegan and vegetarian diets on hip fracture risk. Additionally, the inclusion of a large sample size across the studies ensured high statistical power, increasing the reliability of the findings.

When interpreting the findings of this study, some limitations must be considered. First, the absence of detailed information on dietary quality in most studies constitutes a significant limitation. The quality of vegetarian and vegan diets is highly variable, and even within these dietary patterns, the consumption of less-healthy plant-based foods may impact bone health differently compared with more nutrient-dense plant foods. This variation also extends to the intake of critical nutrients,

such as calcium and vitamin D. Second, key details include the duration, adherence, and maintenance of vegetarian and vegan diets. This was not assessable, as this information was not provided in all studies. Furthermore, 3 of the studies[14,15,17] included only European participants, while 1 study[16] included North American participants, limiting the generalizability of the findings to other populations or ethnic groups. This limitation is particularly relevant given the known ethnic variations in BMD and fracture risk.[42] Finally, the reliance on self-reported data introduces potential bias, as these measures are subject to inaccuracies, including recall bias and reporting errors.

Further studies may be necessary to address data related to vertebral fractures, which can often be asymptomatic but represent the most common osteoporotic fracture and indicate high risk for future fractures.[30] Future research should further explore the underlying mechanisms and potential dietary interventions to enhance bone health and reduce hip fractures in individuals following vegetarian and vegan lifestyles.

It is essential to develop specific clinical guidelines to safeguard bone health in vegetarians and vegans. These should include raising awareness about the importance of adequate intake of key nutrients; recommendations for appropriate supplementation, when necessary; resistance exercise interventions; and regular screening, such as BMD assessments, to reduce the incidence of hip fractures and improve overall bone health in individuals following vegetarian and vegan diets.

CONCLUSION

In conclusion, we found that adherence to vegetarian and vegan diets was associated with a higher risk of hip fracture. The findings underscore the importance of considering dietary choices when addressing bone health, particularly in populations adopting plant-based diets. A carefully considered selection of foods is essential to mitigate the risks associated with these diets; incorporating nutrient-rich options can help ensure adequate intake of calcium, vitamin D, and other critical nutrients for bone health. Additionally, if deficiencies are identified, the use of supplements may be necessary to compensate for these gaps. With the growing adoption of vegetarian and vegan diets, healthcare professionals should prioritize providing evidence-based education and support, including individualized dietary counseling by registered dietitians and nutritionists.

Author Contributions. R.S.B. and T.L.: conceptualization, investigation, methodology, formal analysis, and writing—original draft; M.F.M., P.S.A., V.d.S.N.N., D.S., and M.H.: formal analysis, and writing—review and editing; D.E.: conceptualization, project administration, supervision, methodology, investigation, and writing—review and editing. All authors made the final approval of the version to be submitted and agree to be accountable for all aspects of the work. R.S.B. and T.L. equally contributed to the article.

Supplementary Material

Supplementary Material is available at *Nutrition Reviews* online.

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Conflicts of Interest

None declared.

Data Availability

This systematic review is based on previously published studies. No new primary data were generated or collected for this study. All data extracted from included studies are available within the article and its supplementary materials.

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