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ORIGINAL ARTICLES

Associations between combined dietary inflammatory and oxidative stress risk scores and osteoporosis: a population-based analysis of graded risk

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ABSTRACT

Summary: This cross-sectional study analyzed data from the National Health and Nutrition Examination Survey (NHANES) to examine the association between the dietary inflammatory index (DII) and dietary oxidative balance score (DOBS) with osteoporosis risk using multivariable logistic regression models. The results showed that a high DII and low DOBS were significantly associated with increased osteoporosis risk, particularly in women.

Purpose: This cross-sectional study aimed to investigate the association between dietary inflammatory potential, as measured by the dietary inflammatory index (DII), and dietary oxidative balance score (DOBS), with osteoporosis risk in a large, nationally representative sample. Gender-specific analyses were conducted to assess potential differences in these associations.

Methods: Data from the National Health and Nutrition Examination Survey (NHANES) cycles 2007–2008, 2009–2010, 2013–2014, and 2017–2018 were utilized, including 10,709 participants. DII and DOBS scores were calculated based on 24-hour dietary recalls, and participants were stratified into composite dietary risk groups. Osteoporosis was defined based on dual-energy X-ray absorptiometry (DXA) measurements. Multivariable logistic regression models were used to estimate the odds ratios (ORs) for osteoporosis across dietary risk groups, adjusting for demographic, lifestyle, and clinical factors. Subgroup analyses were conducted for male and female participants.

Results: In the overall participants, participants in the high-risk dietary group (high DII, low DOBS) had a significantly higher odds of osteoporosis compared to the low-risk group (Model 3: OR: 2.31, 95% CI: 1.39-3.85, P = 0.002). In gender-stratified analyses, women in the high-risk group had a more than twofold increased odds of osteoporosis compared to the low-risk group (Model 3: OR: 2.71, 95% CI: 1.49–4.93, P = 0.002), whereas in men, the association between dietary risk groups and osteoporosis was not statistically significant (Model 3: OR: 1.61, 95% CI: 0.73–3.57, P = 0.235).

Conclusion: Dietary patterns with high inflammatory potential and low antioxidant intake are associated with an increased risk of osteoporosis, particularly in women. Given the cross-sectional design, causal relationships cannot be established, and prospective studies are warranted to further clarify these associations.

Keywords: Bone mineral density; Dietary inflammatory index; Oxidative balance score; Combined dietary risk classification; Osteoporosis; NHANES.

INTRODUCTION

Osteoporosis is a prevalent metabolic bone disorder, particularly affecting older adults, and is a leading cause of fractures globally[1]. The condition, characterized by decreased bone mineral density (BMD) and compromised bone strength, significantly increases the risk of fractures, particularly hip and vertebral fractures, leading to a substantial burden on healthcare systems and reduced quality of life among affected individuals. With the aging global population, the incidence of osteoporosis and related fractures is expected to rise, making the identification of modifiable risk factors critical for prevention strategies[2]. Traditionally, the focus on osteoporosis prevention has centered around adequate intake of calcium and vitamin D[3]. However, recent studies have highlighted the potential role of dietary

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patterns that influence inflammation and oxidative stress in the pathogenesis of osteoporosis. Both chronic inflammation and oxidative stress have been implicated in accelerated bone resorption and impaired bone formation, processes that contribute to bone fragility and increased fracture risk[4–6]. This evolving understanding suggests that diets promoting systemic inflammation or lacking in antioxidants may have deleterious effects on bone health.

The dietary inflammatory index (DII) is a widely used tool designed to assess the inflammatory potential of a diet, where higher DII scores reflect more pro-inflammatory dietary patterns[7]. Meanwhile, the dietary oxidative balance score (DOBS) estimates the balance between dietary antioxidants and pro-oxidants, with higher scores indicating a more antioxidant-rich diet[8]. Both indices have been linked to various chronic diseases, such as cardiovascular disease, diabetes, and cancer. However, their combined impact on bone health and osteoporosis risk remains less explored, particularly when these dietary factors are assessed together.

In this cross-sectional study, we aim to investigate the relationship between combined dietary risk, as measured by DII and DOBS, and the risk of osteoporosis using data from the National Health and Nutrition Examination Survey (NHANES). To achieve balanced group sizes and enhance the interpretability of the dose-response relationship, we classified participants into composite dietary risk groups using tertiles of DII and DOBS. Additionally, recognizing the physiological differences between men and women in bone metabolism, we conducted subgroup analyses to determine whether the associations between dietary risk groups and osteoporosis differ by gender.

MATERIALS AND METHODS

Study population

This study utilized data from four NHANES cycles (2007–2008, 2009–2010, 2013–2014, and 2017–2018), which included a total of 40,115 participants. NHANES is a cross-sectional survey designed to collect health and nutrition data from a nationally representative sample of the non-institutionalized U.S. civilian population. The survey uses a complex, multistage probability sampling design. Participants underwent in-home interviews, followed by physical examinations and laboratory assessments at mobile examination centers. Only participants with complete data who met the predefined inclusion criteria were considered for analysis, as shown in Figure 1. After applying exclusion cri-

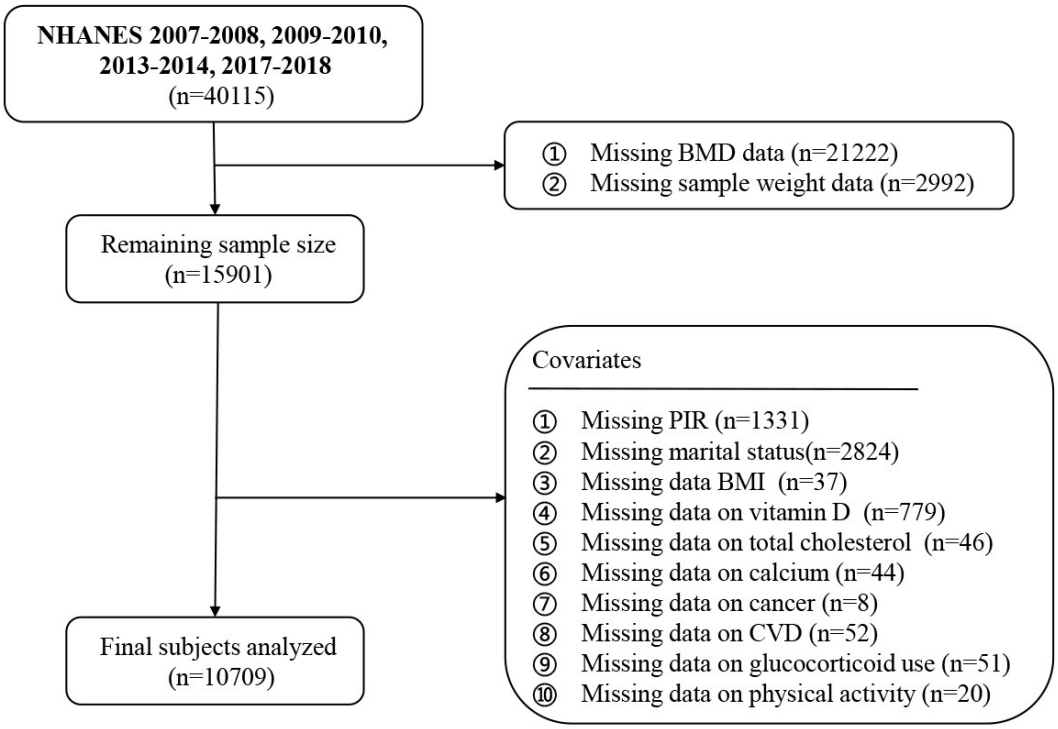

Figure 1. Flowchart of the study population selection process.
NHANES: National Health and Nutrition Examination Survey, BMD: Bone mineral density, PIR: Poverty-to-income ratio, BMI: Body mass index, CVD: Cardiovascular disease.

teria, a total of 10,709 participants remained eligible for the final analysis.

Outcome assessment

The primary outcome of this study was the diagnosis of osteoporosis, determined by bone mineral density (BMD) measurements using dual-energy X-ray absorptiometry (DXA) with Hologic QDR 4500A fan-beam densitometers. BMD was measured at the four femoral regions, following standardized NHANES protocols. Osteoporosis was defined according to the diagnostic criteria set by the World Health Organization (WHO), where a BMD value 2.5 standard deviations (SD) or more below the mean BMD of a young adult reference population is indicative of osteoporosis. The reference BMD values were derived from the femoral BMD of non-Hispanic white women aged 20–29 years, as established in the NHANES III dataset[9].

Exposure assessment

Dietary data for this study were obtained from two 24-hour dietary recall interviews as part of NHANES, with the first interview conducted in person at a mobile examination center (MEC) and the second by telephone 3 to 10 days later. The average of the two recalls was used for analysis. Two dietary scores were calculated: the dietary inflammatory index (DII) and the dietary oxidative balance score (DOBS). The DII was derived using nutrient intake data for key dietary components, including carbohydrates, fats, proteins, and several vitamins and minerals, following established methods[10]. Each nutrient's intake was compared against a global reference database to compute z-scores, which were then multiplied by the respective inflammatory effect scores based on nearly 2,000 peer-reviewed studies. Higher DII values indicate more pro-inflammatory diets, while lower values reflect anti-inflammatory diets. The DOBS was calculated based on 16 dietary components, including 14 antioxidants (such as fiber, carotene, vitamins C and E, and magnesium) and 2 pro-oxidants (total fat and iron). For each nutrient, intake levels were categorized into sex-specific tertiles, with antioxidants assigned higher scores for greater intake (2 for high, 1 for moderate, and 0 for low), and pro-oxidants scored inversely (2 for low, 1 for moderate, and 0 for high). The total DOBS was the sum of all component scores, with higher values indicating a more antioxidant-rich diet [8]. The detailed scoring scheme, including all cut-off values and the antioxidant/pro-oxidant designation for each component, is provided in Supplementary Table I.

Participants were stratified into three risk groups: low-risk, medium-risk, and high-risk, based on the combination of DII and DOBS tertiles. The highest tertile of DII (indicating a pro-inflammatory diet) and the lowest tertile of DOBS (reflecting low antioxidant intake) were classified as the high-risk group. Conversely, the lowest tertile of DII (indicating an anti-inflammatory diet) and the highest tertile of DOBS (rich in antioxidants) were classified as the low-risk group. All other combinations of DII and DOBS scores (e.g., moderate DII with high DOBS, or low DII with moderate DOBS) formed the medium-risk group. Tertile-based grouping was chosen because it provides more balanced group sizes and greater statistical stability than quartile stratification, particularly in large-scale population studies involving composite dietary indices. This approach also minimizes the occurrence of sparse or empty subgroups, which can arise with more granular categorization and potentially reduce statistical power. The use of tertile categorization for dietary indices is well established and widely applied in nutritional epidemiology to optimize interpretability and comparability across studies[11,12]. We conducted preliminary analyses using both tertiles and quartiles; however, quartile stratification resulted in some risk group combinations with very small or empty cell counts, leading to unstable estimates (Supplementary Table II). Therefore, tertiles were selected for the main analysis, consistent with prior literature.

Covariates

A range of demographic, lifestyle, and clinical variables were included as covariates to account for potential confounding factors. Demographic variables included age, gender, race/ethnicity (Mexican American, Non-Hispanic Black, Non-Hispanic White, and Other), and the poverty-income ratio (PIR), all obtained from NHANES demographic data. Marital status was categorized as never married, married or cohabiting, and widowed, divorced, or separated. Body mass index (BMI) was calculated from measured height and weight. Lifestyle factors included physical activity, categorized as sedentary, low, moderate, or high, and glucocorticoid use (yes/no). Clinical covariates included serum levels of vitamin D, albumin, calcium, and total cholesterol, which were measured in NHANES mobile examination centers under standardized protocols. The presence of comorbidities, including cardiovascular disease (CVD), cancer, and diabetes, was determined based on self-reported diagnoses or the use of relevant medications.

Statistical analysis

Descriptive statistics were used to summarize the baseline characteristics of the study population. Continuous variables were presented as means ± standard deviations (SD). Categorical variables were expressed as numbers and percentages. Group differences in continuous variables were assessed using Student's t-test or Wilcoxon rank-sum test, and categorical variables were

TABLE I. Baseline characteristics of the study participants

Characteristic	Overall, n = 10709 (100%)	Status		p-value
		None, n = 10159 (96%)	Osteoporosis, n = 550 (4.2%)	
Age	51.8 ± 15.9	51.0 ± 15.6	69.2 ± 10.7	<0.001
Gender				<0.001
Female	5,396.0 (51.6%)	5,014.0 (50.6%)	382.0 (74.5%)	
Male	5,313.0 (48.4%)	5,145.0 (49.4%)	168.0 (25.5%)	
Race				<0.001
Mexican American	1,602.0 (7.2%)	1,561.0 (7.4%)	41.0 (3.1%)	
Non Hispanic Black	1,929.0 (9.4%)	1,881.0 (9.6%)	48.0 (4.3%)	
Non Hispanic White	5,337.0 (72.0%)	4,966.0 (71.5%)	371.0 (82.8%)	
Other race	1,841.0 (11.4%)	1,751.0 (11.5%)	90.0 (9.8%)	
PIR				<0.001
< 1	1,940.0 (12.0%)	1,844.0 (12.0%)	96.0 (12.8%)	
1-3	4,489.0 (33.9%)	4,202.0 (33.3%)	287.0 (47.7%)	
> 3	4,280.0 (54.1%)	4,113.0 (54.7%)	167.0 (39.4%)	
Marital status				<0.001
Never married	1,387.0 (13.6%)	1,350.0 (14.0%)	37.0 (4.7%)	
Married or cohabiting	6,708.0 (66.0%)	6,448.0 (66.8%)	260.0 (47.4%)	
Widowed, divorced or separated	2,614.0 (20.4%)	2,361.0 (19.2%)	253.0 (47.9%)	
BMI	28.5 ± 5.8	28.6 ± 5.8	25.5 ± 5.1	<0.001
Vitamin D	72.7 ± 28.8	72.2 ± 28.0	84.2 ± 42.2	<0.001
Albumin	42.5 ± 3.2	42.6 ± 3.1	41.3 ± 3.3	<0.001
Calcium	2.4 ± 0.1	2.4 ± 0.1	2.4 ± 0.1	>0.9
Total cholesterol	5.1 ± 1.1	5.1 ± 1.1	5.2 ± 1.2	0.063
Physical activity				<0.001
Sedentary	2,778.0 (21.3%)	2,524.0 (20.7%)	254.0 (36.8%)	
Low	2,894.0 (28.0%)	2,740.0 (27.8%)	154.0 (32.1%)	
Moderate	2,602.0 (26.9%)	2,519.0 (27.2%)	83.0 (19.3%)	
High	2,435.0 (23.8%)	2,376.0 (24.3%)	59.0 (11.8%)	
Glucocorticoid use				0.013
No	10,154.0 (94.6%)	9,647.0 (94.9%)	507.0 (88.8%)	
Yes	555.0 (5.4%)	512.0 (5.1%)	43.0 (11.2%)	
CVD				<0.001
No	9,380.0 (90.0%)	8,974.0 (90.7%)	406.0 (74.4%)	
Yes	1,329.0 (10.0%)	1,185.0 (9.3%)	144.0 (25.6%)	
Cancer				<0.001
No	9,423.0 (87.9%)	8,997.0 (88.3%)	426.0 (77.3%)	
Yes	1,286.0 (12.1%)	1,162.0 (11.7%)	124.0 (22.7%)	
Diabetes				0.055
No	4,077.0 (36.4%)	3,865.0 (36.5%)	212.0 (35.1%)	
Yes	1,963.0 (13.5%)	1,842.0 (13.3%)	121.0 (18.9%)	
Unclear	4,669.0 (50.1%)	4,452.0 (50.3%)	217.0 (46.1%)	
DII				<0.001
T1	3,570.0 (36.4%)	3,426.0 (36.9%)	144.0 (25.7%)	
T2	3,570.0 (34.2%)	3,394.0 (34.4%)	176.0 (28.0%)	
T3	3,569.0 (29.4%)	3,339.0 (28.7%)	230.0 (46.3%)	
DOBS				<0.001
T1	3,570.0 (28.7%)	3,341.0 (28.3%)	229.0 (39.7%)	
T2	3,570.0 (34.0%)	3,403.0 (34.1%)	167.0 (32.5%)	
T3	3,569.0 (37.2%)	3,415.0 (37.7%)	154.0 (27.8%)	

PIR: poverty-income ratio; DII: dietary inflammatory index; DOBS: Dietary oxidative balance score

TABLE II. Dietary risk table based on OBS and DII

DII	DOBS		
	T1	T2	T3
T1	0.3% (Medium)	6.6% (Medium)	26.4% (Low)
T2	6.4% (Medium)	20.3% (Medium)	6.7% (Medium)
T3	26.7% (High)	6.4% (Medium)	0.2% (Medium)

DOBS: Dietary oxidative balance score; DII: dietary inflammatory index

compared using the chi-square test. The primary outcome, osteoporosis, was treated as a binary variable. To evaluate the association between the newly created risk groups and osteoporosis, multivariable logistic regression models were employed. The low-risk group served as the reference group in all models. Model 1 adjusted for demographic factors, including age, gender, race/ethnicity, PIR and marital status. Model 2 included additional adjustments for BMI, physical activity, vitamin D, albumin, calcium and total cholesterol. Model 3 additionally adjusted for glucocorticoid use and the presence of comorbidities, including diabetes, cardiovascular disease (CVD), and cancer. Odds ratios (ORs) with 95% confidence intervals (CIs) were calculated to estimate the strength of association in each model. Furthermore, P-values for trend (P-trend) were calculated by treating the risk groups as ordinal variables, allowing for the assessment of potential dose-response relationships. In addition to the overall analysis, subgroup analyses were conducted to explore the relationship between the newly defined risk groups and osteoporosis within different gender groups. Separate multivariable logistic regression models were fitted for male and female participants to assess potential sex-specific associations. The same set of adjustments used in the primary analysis was applied to both subgroup models, including demographic factors, BMI, lifestyle variables, and comorbidities. All statistical tests were two-sided, with a significance level set at $P < 0.05$. Analyses were performed using R software (version 4.4.0).

RESULTS

Participant characteristics

Table I presents the baseline characteristics of the study population, stratified by osteoporosis status. A total of 10,709 participants were included in the analysis, of whom 550 (4.2%) were diagnosed with osteoporosis. The mean age of participants with osteoporosis was significantly higher than those without the condition (69.2 ± 10.7 years vs. 51.0 ± 15.6 years, $P < 0.001$). Women accounted for 74.5% of the osteoporotic group, compared to 50.6% in the non-osteoporotic group ($P < 0.001$). Osteoporosis was more prevalent among Non-Hispanic Whites (82.8%, $P < 0.001$). Participants with osteoporosis had a lower mean BMI (25.5 ± 5.1 vs. 28.6 ± 5.8, $P < 0.001$) and lower serum albumin levels (41.3 ± 3.3 g/L vs. 42.6 ± 3.1 g/L, $P < 0.001$). They were also more likely to lead a sedentary lifestyle (36.8% vs. 20.7%, $P < 0.001$). Osteoporosis was associated with a higher prevalence of glucocorticoid use (11.2% vs. 5.1%, $P = 0.013$), cardiovascular disease (CVD) (25.6% vs. 9.3%, $P < 0.001$), and cancer (22.7% vs. 11.7%, $P < 0.001$). In terms of dietary patterns, participants with osteoporosis were more likely to be in the highest tertile of the DII (46.3%, $P < 0.001$) and the lowest tertile of the DOBS (39.7%, $P < 0.001$). Based on the composite risk groups derived from DII and DOBS, participants were categorized into three risk groups: low-risk, medium-risk, and high-risk. Of the 10,709 participants, 26.7% were classified as high-risk, 26.4% as low-risk, and the remaining 46.9% as medium-risk (Table II).

The distribution of DII and DOBS across the composite dietary risk groups is summarized in Supplementary Table III and visually depicted in Figure 2. As shown in Figure 2A, participants in the high-risk group exhibited substantially higher DII values, reflecting a more pro-inflammatory dietary pattern, whereas the low-risk group showed the lowest DII values. Conversely, as shown in Figure 2B, the high-risk group had the lowest DOBS scores, indicating poorer dietary antioxidant balance, while the low-risk group had the highest DOBS scores.

Association between risk groups and osteoporosis

In Model 1, participants in the high-risk group demonstrated a significantly increased risk of osteoporosis, with an odds ratio (OR) of 2.02 (95% CI: 1.27, 3.20) compared to the low-risk group ($P = 0.004$). The medium-risk group showed a non-significant increase in risk with an OR of 1.23 (95% CI: 0.79, 1.91) ($P = 0.355$). The P for trend was 0.004, indicating a significant grad-

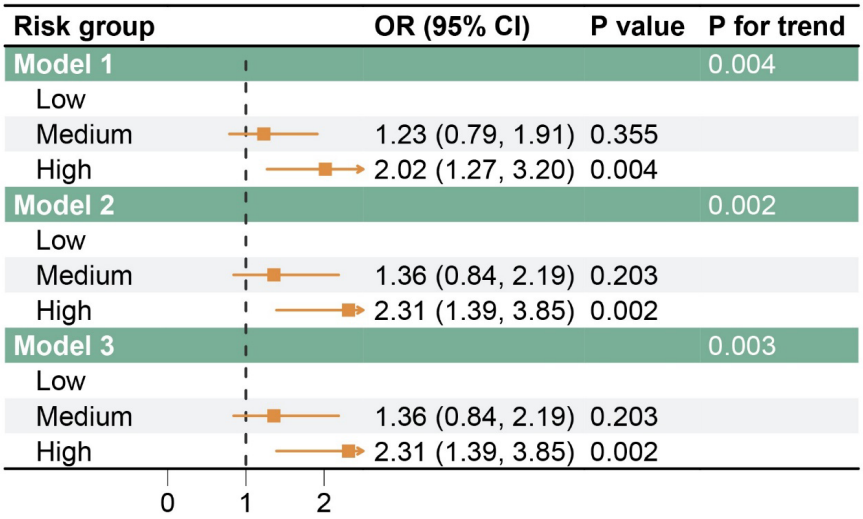

Figure 2. Distribution of DII and DOBS by composite dietary risk group. (A) Beeswarm plot illustrating the distribution of DII scores across composite dietary risk groups. (B) Beeswarm plot showing the distribution of DOBS scores by composite dietary risk group. DII: dietary inflammatory index, DOBS: dietary oxidative balance score.

ed relationship between increasing dietary risk and osteoporosis, suggesting that the higher the dietary risk score, the greater the likelihood of developing osteoporosis. In Model 2, after adjusting for BMI, physical activity, serum vitamin D, albumin, calcium, and total cholesterol, the association strengthened. The OR for the high-risk group increased to 2.31 (95% CI: 1.39, 3.85) (P = 0.002), while the medium-risk group had an OR of 1.36 (95% CI: 0.84, 2.19), which remained non-significant (P = 0.203). The P for trend was 0.002, reinforcing the existence of a dose-response effect, with a clear increase in osteoporosis risk corresponding to higher dietary risk scores. In Model 3, the high-risk group continued to exhibit a significantly elevated risk of osteoporosis with an OR of 2.31 (95% CI: 1.39, 3.85) (P = 0.002). The OR for the medium-risk group remained 1.36 (95% CI: 0.84, 2.19) (P = 0.203), with a P for trend of 0.003 (Figure 3). These results demonstrate a strong association between the risk group and osteoporosis, particularly in the high-risk group, where the risk of osteoporosis was more than doubled compared to the low-risk group. The consistent and significant P for trend across all models suggests a graded, dose-response relationship, indicating that as the combined dietary risk score increases, so does the risk for osteoporosis, reflecting the cumulative impact of dietary inflammation and oxidative stress on bone health.

Subgroup analysis

To further explore the association between dietary risk groups and osteoporosis, subgroup analyses were conducted separately for male and female participants. The results are shown in Figure 4. Among male participants, no statistically significant associations were observed between the dietary risk groups and osteoporosis across the different models. In the fully adjusted model (Model 3), the odds ratio (OR) for osteoporosis in the high-risk group compared to the low-risk group was 1.61 (95% CI: 0.73–3.57, P = 0.235), indicating a positive but non-significant association. Similarly, the medium-risk group had an OR of 0.99 (95% CI: 0.45–2.21, P = 0.984) compared to the low-risk group. These findings suggest that, in males, the association between dietary risk and osteoporosis may not be as strong or as clear. In contrast, a stronger and statistically significant association was found among female participants. In Model 3, women in the high-risk group had a significantly higher odds of osteoporosis compared to those in the low-risk group, with an OR of 2.71 (95% CI: 1.49–4.93, P = 0.002). The medium-risk group also showed an increased, though not statistically significant, risk (OR: 1.57, 95% CI: 0.89–2.78). The P for trend across risk groups in females was 0.003, indicating a significant dose-response relationship, where higher dietary risk corresponded to an increased likelihood of osteoporosis. The gender-stratified analyses reveal a notable difference between males and females in the association between dietary risk and osteoporosis. While the relationship was more pronounced and statistically significant in females, it was weaker and non-significant in males.

DISCUSSION

This study investigated the association between dietary

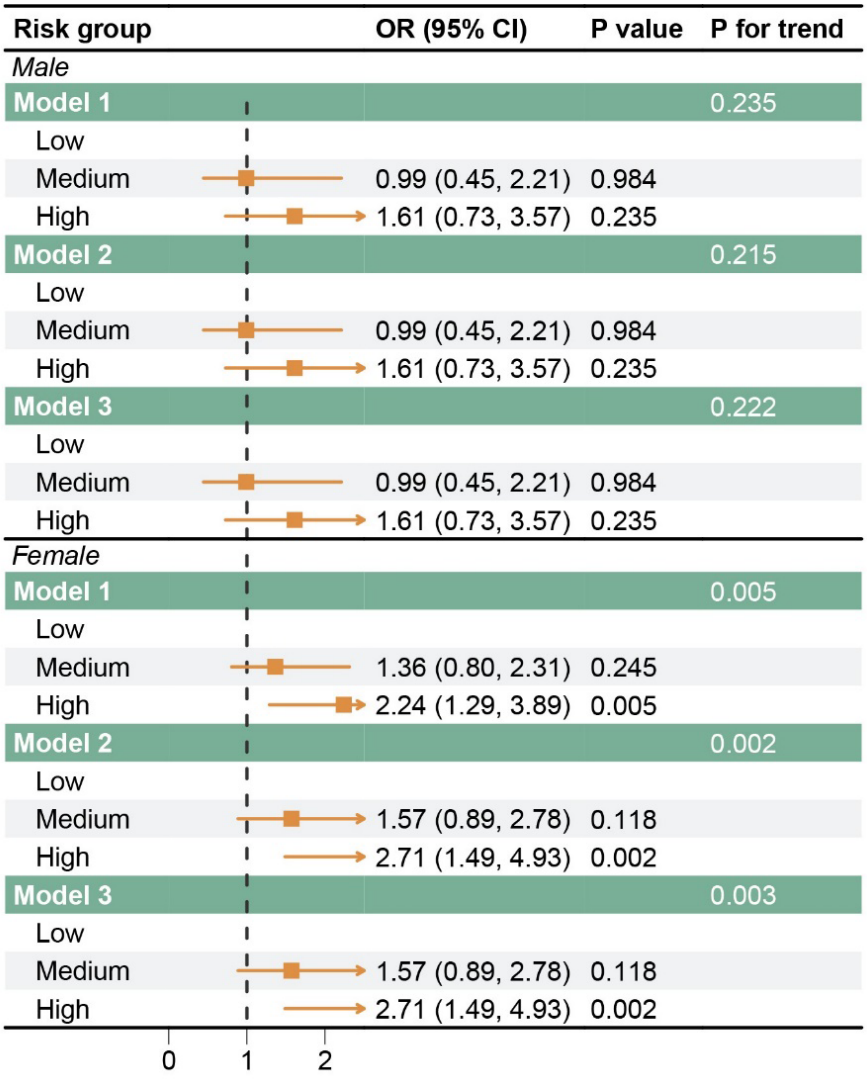

Figure 3. Associations between dietary risk groups and osteoporosis in overall participants.
Forest plots display the odds ratios (ORs) and 95% confidence intervals (CIs) for osteoporosis risk by composite dietary risk group (Low, Medium, High) in the total study population. Results are shown for three sequentially adjusted logistic regression models. Compared to the low-risk group, participants in the high-risk group had significantly increased odds of osteoporosis across all models. (Model 1, adjusted for age, gender, race/ethnicity, PIR and marital status; Model 2, further adjusted for BMI, physical activity, vitamin D, albumin, calcium and total cholesterol; Model 3, with additional adjustments for glucocorticoid use, diabetes, CVD and cancer). OR: Odds ratio, CI: Confidence interval, CVD: Cardiovascular disease.

inflammatory potential and oxidative balance—measured by the Dietary Inflammatory Index (DII) and the Dietary Oxidative Balance Score (DOBS), respectively—and osteoporosis in a nationally representative sample. Our findings suggest that higher DII and lower DOBS scores are significantly associated with an increased risk of osteoporosis, particularly among women. These results emphasize the important role of diet—particularly its inflammatory and oxidative properties—in influencing bone health.

A key finding of this study is the significant association between high dietary risk (characterized by high DII and low DOBS) and osteoporosis among women. Women in the high-risk group had a notably higher likelihood of osteoporosis compared to those in the low-risk group, even after adjusting for various confounders. In men, although a similar trend was observed, the association was not statistically significant. These gender-specific results may reflect underlying biological differences in bone metabolism, particularly related to the protective effect of estrogen, which declines after menopause[13]. This may make women more susceptible to the detrimental effects of pro-inflammatory and antioxidant-deficient diets. The association

between pro-inflammatory diets and reduced antioxidant intake has been well-documented in their contribution to systemic inflammation and oxidative stress[14], both of which play crucial roles in bone resorption and impaired bone formation[15,16]. Increased osteoclast activity, driven by inflammation, and oxidative damage to osteoblasts can accelerate bone loss and increase fracture risk. This mechanistic link helps to explain the observed relationship between dietary risk and osteoporosis.

While traditional research has focused on calcium and vitamin D as key nutrients in osteoporosis prevention, recent studies have highlighted the broader impact of dietary patterns. Pro-inflammatory diets, rich in refined carbohydrates and saturated fats, have been shown to exacerbate bone loss through heightened inflammatory responses[17]. Similarly, low antioxidant intake, as reflected by lower DOBS scores, has been associated with oxidative stress, which further disrupts bone remodeling[18]. Our findings are consistent with these studies but extend the current understanding by simultaneously evaluating both inflammation and oxidative balance, thereby providing a more comprehensive perspective on the role of diet in bone health.

This study has several notable strengths. First, it utilizes data from the NHANES survey, a nationally representative and well-characterized dataset, which enhances the generalizability of our findings to the U.S. population. Second, by incorporating both DII and DOBS, we were able to assess the combined effects of dietary inflammation and oxidative stress, providing a more comprehensive understanding of diet's influence on bone health. Additionally, the use of multivariable adjustment for demographic, lifestyle, and clinical factors strengthens the validity of the results.

However, several limitations should be emphasized. Most importantly, the cross-sectional nature of this study precludes any inference of causality between dietary patterns and osteoporosis risk. Our findings should be interpreted as associations rather than evidence of causation. Longitudinal studies and randomized controlled trials are required to determine whether pro-inflammatory and antioxidant-poor diets directly contribute to bone loss over time. Furthermore, dietary intake was assessed using 24-hour dietary recalls, which may not fully capture long-term dietary habits and are subject to recall bias. Finally, the DII and DOBS rely on estimated nutrient intakes rather than direct biomarkers, which could introduce measurement error. Future research should focus on prospective studies to clarify the temporal relationship between diet, inflammation, oxidative stress, and bone health. Randomized controlled trials investigating the effects of anti-inflammatory diets on bone health outcomes would also provide stronger evidence to inform clinical practice. Additionally, further research into the biological pathways linking dietary factors and bone metabolism, especially in relation to gender differences, is warranted.

CONCLUSION

In summary, this study demonstrates a significant association between dietary patterns characterized by high inflammatory potential and low antioxidant intake and an increased risk of osteoporosis, particularly in women. These findings highlight the importance of considering both inflammatory and oxidative properties of the diet in the context of bone health. However, due to the cross-sectional design of this study, causality cannot be established, and our results should be interpreted as associations rather than causal effects. Further prospective research, including longitudinal cohort studies and randomized controlled trials, is needed to clarify causal relationships and to explore the biological mechanisms underlying gender-specific differences. Dietary interventions aimed at reducing inflammation and enhancing antioxidant intake may offer a promising approach for osteoporosis prevention, particularly in high-risk populations.

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SUPPLEMENTARY MATERIAL

Calculation of the Dietary Oxidative Balance Score (DOBS)

The DOBS was constructed to quantify the overall balance between dietary antioxidants and pro-oxidants. Sixteen dietary components were included, comprising 14 antioxidants (e.g., dietary fiber, carotene, vitamins C and E, magnesium) and 2 pro-oxidants (total fat and iron). For each nutrient, sex-specific tertile cut-off values were determined based on the study population. For antioxidant components, higher intake received higher scores (0 = lowest tertile, 1 = middle tertile, 2 = highest tertile), whereas for pro-oxidant components, the scoring was reversed (2 = lowest tertile, 1 = middle tertile, 0 = highest tertile). The total DOBS was calculated as the sum of the component scores, with higher values indicating a diet richer in antioxidants relative to pro-oxidants.The specific scoring criteria and cut-off values for each dietary component, stratified by sex, are detailed in Supplementary Table I.

Example of DOBS Calculation:

Suppose a female participant has the following dietary intakes:

(1) Dietary fiber: 12 g/day (middle tertile for females, assigned 1 point)
(2) Total fat: 80 g/day (highest tertile for females, assigned 0 points, as it is a pro-oxidant)
... (continue for other nutrients as needed)

The DOBS for this participant would be calculated by summing the assigned scores across all 16 components.

SUPPLEMENTARY TABLE I. Scheme for assigning the dietary oxidative balance score components

DOBS components	Property	Female			Male		
		0	1	2	0	1	2
Dietary fiber (g/d)	A	< 11.25	11.25 - 17.15	≥ 17.15	< 13.20	13.20 - 20.80	≥ 20.80
Carotene (RE/d)	A	< 637.50	637.50 - 2193.67	≥ 2193.67	< 615.17	615.17 - 2001.83	≥ 2001.83
Riboflavin (mg/d)	A	< 1.38	1.38 - 1.98	≥ 1.98	< 1.74	1.74 - 2.55	≥ 2.55
Niacin (mg/d)	A	< 16.01	16.01 - 22.71	≥ 22.71	< 21.77	21.77 - 31.33	≥ 31.33
Vitamin B_6 (mg/d)	A	< 1.29	1.29 - 1.88	≥ 1.88	< 1.70	1.70 - 2.51	≥ 2.51
Total folate (mcg/d)	A	< 258.50	258.50 - 379.50	≥ 379.50	< 322.83	322.83 - 488.50	≥ 488.50
Vitamin B_{12} (mcg/d)	A	< 2.60	2.60 - 4.47	≥ 4.47	< 3.58	3.58 - 6.12	≥ 6.12
Vitamin C (mg/d)	A	< 40.87	40.87 - 90.43	≥ 90.43	< 42.45	42.45 - 101.07	≥ 101.07
Vitamin E (ATE) (mg/d)	A	< 4.75	4.75 - 7.65	≥ 7.65	< 5.89	5.89 - 9.18	≥ 9.18
Calcium (mg/d)	A	< 614.50	614.50 - 916.00	≥ 916.00	< 722.50	722.50 - 1109.00	≥ 1109.00
Magnesium (mg/d)	A	< 206.50	206.50 - 286.00	≥ 286.00	< 257.00	257.00 - 358.50	≥ 358.50
Zinc (mg/d)	A	< 7.12	7.12 - 10.25	≥ 10.25	< 9.57	9.57 - 14.06	≥ 14.06
Copper (mg/d)	A	< 0.86	0.86 - 1.21	≥ 1.21	< 1.04	1.04 - 1.48	≥ 1.48
Selenium (mcg/d)	A	< 72.00	72.00 - 102.58	≥ 102.58	< 99.20	99.20 - 139.75	≥ 139.75
Total fat (g/d)	P	≥ 73.41	49.72 - 73.41	< 49.72	≥ 98.20	66.22 - 98.20	< 66.22
Iron (mg/d)	P	≥ 13.99	9.67 - 13.99	< 9.67	≥ 20.80	13.20 - 20.80	< 13.20

DOBS: Dietary oxidative balance score; A: antioxidant; P: prooxidant; RE: retinol equivalent; ATE: alpha-tocopherol equivalent

SUPPLEMENTARY TABLE II. Distribution of combined DII and DOBS risk groups based on quartile stratification

DII	DOBS			
	Q1	Q2	Q3	Q4
Q1	-	0.6% (Medium)	5.6% (Medium)	18.8% (Low)
Q2	0.5% (Medium)	6.4% (Medium)	12.6% (Medium)	5.6% (Medium)
Q3	5.5% (Medium)	12.7% (Medium)	6.3% (Medium)	0.6% (Medium)
Q4	19.1% (High)	5.4% (Medium)	0.5% (Medium)	-

DOBS: Dietary oxidative balance score; DII: dietary inflammatory index

SUPPLEMENTARY TABLE III. Mean and standard deviation of DII and DOBS by composite dietary risk group

	High Risk	Low Risk	Medium Risk
DII	3.21 (0.61)	-1.45 (1.12)	1.19 (0.98)
DOBS	7.55 (2.47)	24.30 (2.44)	16.13 (3.73)

DOBS: Dietary oxidative balance score; DII: dietary inflammatory index