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A pilot study on the correlation between dietary habits and osteoporosis in men living in the frigid regions of China

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Abstract

Objective: To analyze the risk of osteoporosis among middle-aged men in the cold regions of China (Heilongjiang Province) and provide theoretical support for the early identification of high-risk populations. **Methods:** Bone mineral density (BMD) data were collected from male subjects aged 50-65 who met the inclusion criteria at the physical examination center of a hospital in Harbin between August to December 2022. General clinical data and dietary information were obtained through face-to-face interviews using a dietary questionnaire survey. **Results:** The prevalence of osteoporosis and osteopenia was 14.38% and 52.06%, respectively, while normal bone mass accounted for 33.56%. Significant differences were observed among groups in smoking habits, sunlight exposure, exercise levels, and dietary patterns at each bone mass level. The BMD of the lumbar spine, femoral neck, and hip showed a negative correlation with the Dietary Inflammatory Index (DII) score. Multivariate logistic regression analysis revealed that smoking and a diet high in oil and salt were positively associated with the risk of osteoporosis. A pro-inflammatory diet was also positively correlated with osteoporosis risk, with individuals in this group being 7.723 times more likely to develop osteoporosis compared to those in the anti-inflammatory diet group. **Conclusion:** The high prevalence of osteoporosis and osteopenia observed in this study highlighted that osteoporosis is a significant and pressing issue among middle-aged men. Smoking, limited sunlight exposure, reduced physical activity, diets high in oil and salt, and pro-inflammatory diets were identified as major risk factors for bone loss. These factors are closely linked to the geography, climate, and cultural practices of cold regions in China. Primary healthcare in this region should focus on the screening and prevention of osteoporosis in middle-aged men by promoting smoking cessation, increased sunlight exposure, adequate vitamin D supplementation, regular physical activity, and adherence to a healthy diet to maintain bone health.

Keywords

osteoporosis; middle-aged men; dietary patterns; bone mineral density; frigid regions; risk factors

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1 Introduction

Osteoporosis (OP) is a systemic bone disease characterized by high morbidity, disability, and mortality rates. Its primary features include increased fracture risk due to bone loss and the deterioration of bone microarchitecture. Among individuals over 50 years old, the prevalence of OP is 19.2%, with a significantly higher rate in women (32.1%) compared to men (6.9%)[1]. Although OP is more common in women, men experience higher rates of disability and mortality following fractures. Furthermore, evaluation and intervention rates for OP are considerably lower in men compared to women[2]. Data also show that men over 50 years old have a 13%-25% lifetime risk of developing osteoporotic fractures, with spinal fractures accounting for 20% and hip fractures for 30% of cases in China[3].

OP is influenced by multiple risk factors, including genetic factors and non-genetic factors[4]. Non-genetic factors play a pivotal role in bone mass loss as individuals age[4]. Nutrients such as calcium, vitamin D, potassium, magnesium, and protein have demonstrated

protective effects on bone mass[5-7]. However, research examining the correlation between dietary patterns, the Dietary Inflammatory Index (DII), and the risk of OP in men is limited. Existing studies on the risk factors for male OP exhibit statistical heterogeneity, and findings vary across different age groups. Moreover, research focused on identifying OP-related risk factors in middle-aged men is scarce. Middle age represents a critical period for early detection and mitigation of risk factors to slow bone mass loss and prevent OP before old age[8]. This study aims to fill this gap by exploring the risk factors for OP in middle-aged men, with a particular focus on dietary patterns and inflammation.

2 Materials and methods

2.1 Research objects and inclusion criteria

A total of 146 men aged 50-65 who met the inclusion criteria were recruited from the health examination center of a hospital in Harbin, Heilongjiang Province, between August and December 2022. The average age of the participants was 55 years. This study was conducted in accordance with the Helsinki Declaration and was approved by the Ethics Committee of the Second Affiliated Hospital of Harbin Medical University (KY2022-209). All participants provided written informed consent prior to their inclusion in the study.

Inclusion criteria: participants were included in the study if they met the following criteria: (1) men aged 50-65 years; (2) permanent residents of Heilongjiang Province since birth; (3) possessed clear cognitive function to independently answer survey questions.

The following individuals were excluded from the study: (1) those with a history of frequent travel or any travel in the past year; (2) individuals with mental illness, poor communication skills, or physical disabilities; (3) those diagnosed with diseases known to affect bone mass, such as: endocrine system disorders, rheumatologic or immune system diseases, and digestive system diseases. Individuals undergoing treatment with medications that influence bone metabolism or gastrointestinal absorption, including vitamin D and calcium supplements, bisphosphonates, glucocorticoids, and chemotherapy drugs. This rigorous selection process ensured that the study population was representative of middle-aged men in the cold regions of Heilongjiang Province, free from confounding factors related to bone mass or metabolism.

2.2 Clinical data

This study utilized a general questionnaire and a dietary survey questionnaire to collect data. The general questionnaire gathered demographic and clinical information, including: (1) personal details: name, age, gender, height, weight, occupation, education level, family income, and place of residence; (2) medical history: fracture history, family history of fractures (including parents), and history of daily medication or nutritional supplement use (*e.g.*, calcium and vitamin D); (3) lifestyle factors: alcohol consumption, smoking history, sunlight exposure duration, exercise habits, and other relevant data.

Dietary survey questionnaire: the dietary questionnaire collected data on food types, frequency, and intake over the past year. The food types were categorized into 14 groups comprising 78 food items, including: cereals, potatoes, vegetables, microorganisms and algae, animal meat, seafood, fruits, nut seeds, dairy and dairy products, beans, eggs, beverages, snacks, and seasonings.

Frequency of consumption: seven options were provided: ≥ 2 times a day, once a day, 4-6 times a week, 2-3 times a week, once a week, < 1 time a week, and almost never.

Consumption quantity: six options were used to estimate food intake: ≤ 50g, > 50-100g, > 100-150g, > 150-200g, > 200-250g, and > 250g.

To calculate nutrient intake, the formula was applied: Nutrient intake = Eating frequency × Single intake × Nutrient content. The average daily intake of nutrients was derived by summing the nutrient values from all food groups. Seasonal variations in specific foods (*e.g.*, seasonal vegetables or fruits) were corrected by applying a factor of 0.25. A comparative food weight map was provided to help participants estimate their food intake. All questionnaires were administered and completed by the same trained investigator to ensure consistency and accuracy.

Bone mineral density (BMD) measurement: BMD was measured using Dual Energy X-ray Absorptiometry (DXA), which is the gold standard for diagnosing OP. Measurements included the lumbar spine (L1-L4), femoral neck (FN), and total hip (TH) in units of g/cm^2. The DXA machine was manufactured by Hologic, USA, with the following specifications: assembly, aperture/filter drum: ASY-05119, assembly, source: 010-0575, assembly, X-Ray Controller: ASY-00409.

The T-score was calculated using the formula: T-score = (Measured BMD - Peak BMD of normal youth of the same race and sex) / Standard deviation of peak BMD of normal youth of the same race and sex.

For men aged ≥ 50 years, the diagnostic criteria recommended by the WHO were applied (Normal: T-score ≥ -1.0; Osteopenia: -2.5 < T-score < -1.0; OP: T-score ≤ -2.5).

Fragility fractures (*e.g.*, hip or vertebral fractures) can be clinically diagnosed as OP without requiring BMD measurement. A diagnosis of OP can also be made in cases of fragility fractures of the proximal humerus, pelvis, or distal forearm when BMD indicates osteopenia (-2.5 < T-score < -1.0).

All BMD measurements were performed by a single professional technician with over 10 years of experience, who had received specialized training and obtained relevant qualification certificates.

2.3 Statistical analysis method

Data were processed and analyzed using Microsoft Excel and SPSS 25.0 statistical software. Descriptive statistics were applied as follows: measurement data conforming to a normal distribution were described using the mean ± standard deviation (SD) and categorical data were described using frequencies and percentages. PCA was utilized to extract dietary data characteristics, followed by orthogonal rotation to construct dietary patterns. The following statistical methods were employed for data analysis: one-way ANOVA was used to compare means across groups for normally distributed data; Kruskal-Wallis H nonparametric test to compare non-normally distributed data; Chi-square test to analyze categorical data; Pearson correlation analysis to evaluate the relationships between variables; and a multivariate logistic regression model to analyze the influencing factors and assess the risk of OP. A two-tailed probability value of $P < 0.05$ was considered statistically significant.

3 Results

A total of 146 men aged 50-65 were enrolled in this study, with an average age of 55 years. The statistics for other general clinical data are presented in Table 1.

3.1 Prevalence of OP

Based on the BMD test results, the 146 subjects were divided into three groups: the OP group including subjects with a T-score ≤ -2.5 SD ($N = 21$), accounting for 14.38%, the osteopenia group including subjects with a T-score between -2.5 SD and -1.0 SD ($N = 76$), accounting for 52.06%, and the Normal bone mass group including subjects with a T-score ≥ -1.0 SD ($N = 49$), accounting for 33.56%. Our findings indicate a significant prevalence of both osteopenia and OP in the study population.

3.2 Single factor analysis of non-dietary influencing factors and bone mass

The results for each group are presented in Table 2. Single-factor analysis revealed no significant differences in age, height, weight, or BMI among the three groups ($P > 0.05$). Similarly, chi-square tests showed no significant differences in education level, occupation, income, fracture history, or drinking history across the groups ($P > 0.05$). However, a significant difference in bone density was observed between individuals with and without a history of smoking ($P < 0.05$). To further explore this relationship, the subjects were categorized into OP and non-OP groups. Chi-square analysis showed that the prevalence of OP among smokers was 10.96%, which was significantly higher than that among non-smokers ($\chi^2 = 5.109$, $P = 0.024$). For fracture history, due to an expected value of less than 5.00 (minimum expected count: 0.43), Fisher's exact test was applied. The result ($P = 0.054$) indicated no statistically significant difference in OP prevalence between individuals with and without a history of fractures. Other factors, including education level, occupation, income, and drinking history, also showed no significant differences between the OP and non-OP groups ($P > 0.05$).

The prevalence of OP in the low-activity, middle-activity group and high-activity groups were 6.85%, 4.11% and 3.42%, respectively. A statistically significant difference was observed in activity levels when comparing the OP, osteopenia, and normal bone mass groups ($\chi^2 = 10.994$, $P = 0.027$). Similarly, the prevalence of OP varied based on daily sunshine exposure: 10.27% for individuals with less than 30 min, 2.74% for those with 30-60 min, and 1.37% for those with more than 60 min. Statistical analysis showed a significant difference in sunshine duration among the OP, osteopenia, and normal bone mass groups ($\chi^2 = 11.572$, $P = 0.021$), as summarized in Table 3.

Table 1 General clinical data of subjects

Item	Group	Number of people (*N*)	Constituent ratio (%)
Age (years)	50-54	62	42.47
	55-59	55	37.67
	60-65	29	19.86
Education Level	Primary school and below	50	34.25
	Middle school	56	38.36
	High school	18	12.32
	College and above	22	15.07
Occupation	Civil servants or institutions	22	15.07
	Administration, service	31	21.23
	Workers	20	13.70
	Farmers	6	4.11
	Freelance	45	30.82
	Retired, unemployment	22	15.07
Monthly household Income (million)	< 0.3	17	11.65
	0.3- < 0.6	47	32.19
	0.6-1	59	40.41
	> 1	23	15.75

Table 2 Comparison of education level, occupation, income, fracture history, smoking history, and alcohol consumption history in relation to bone density across different bone mass subgroups

Item	Osteoporosis	Osteopenia	Normal	*P*
Age (year)	58.000 ± 3.655	55.000 ± 4.290	56.000 ± 3.784	0.059
Height (m)	1.730 ± 0.059	1.733 ± 0.061	1.739 ± 0.051	0.786
Weight (kg)	73.600 ± 15.118	76.500 ± 10.016	77.500 ± 9.972	3.900
Body mass index	24.472 ± 4.205	25.476 ± 10.857	25.620 ± 3.076	3.530
Education level, *n* (%)				0.466
Primary school and below	4 (2.74)	25 (17.12)	21 (14.38)	
Middle school	12 (8.21)	27 (18.49)	17 (11.64)	
High school	2 (1.37)	8 (5.48)	4 (2.74)	
College and above	3 (2.05)	16 (10.96)	7 (4.79)	
Occupation, *n* (%)				0.485
Civil servants or institutions	2 (1.37)	15 (10.27)	5 (3.42)	
Administration, service	7 (4.79)	15 (10.27)	9 (6.16)	
Workers	1 (0.68)	9 (6.16)	10 (6.85)	
Farmers	2 (1.37)	2 (1.37)	2 (1.37)	
Freelance	7 (4.79)	24 (16.44)	14 (9.59)	
Retired, unemployment	2 (1.37)	11 (7.53)	9 (6.16)	
Household income (million), *n* (%)				0.168
< 0.3	1 (0.68)	8 (5.48)	8 (5.48)	
0.3- < 0.6	9 (6.16)	19 (13.01)	19 (13.01)	
0.6-1	6 (4.11)	38 (26.03)	15 (10.27)	
> 1	5 (3.42)	11 (7.53)	7 (4.79)	
Fracture history, *n* (%)	2 (1.37)	1 (0.68)	0	0.054
Family history, *n* (%)	1 (0.68)	6 (4.11)	3 (2.05)	1.000
Smoking history, *n* (%)	16 (10.96)	42 (27.70)	20 (13.70)	0.022
Alcohol consumption, *n* (%)	16 (10.96)	46 (31.51)	28 (19.18)	0.310

Data were present as Mean ± SD or *n* (%).

3.3 Establishment of dietary pattern and comparison of bone mass levels

The dietary pattern in this study was established using principal component analysis with orthogonal rotation. The KMO test statistic was 0.591, and Bartlett's test of sphericity was χ^2 = 111.501, P < 0.001, indicating that the dietary data were relevant and suitable for factor analysis. Principal component analysis was used to extract common factors. The results revealed three significant factors with eigenvalues of 2.037, 1.335, and 1.178, respectively. The variance contribution rates of these factors were 18.52%, 12.13%, and 10.71%, respectively, with a cumulative variance contribution rate of 41.36%. The factor load matrix was obtained through orthogonal rotation to enhance the clarity of the relationships between the original variables and factors. Foods with absolute factor loadings greater than 0.4 were included in the dietary patterns, which were identified as follows: "vegetable-meat-egg dietary pattern", "vegetarian dietary pattern", and "heavy oil and salt dietary pattern". Based on their factor scores, participants were classified into the corresponding dietary patterns. The distribution of each dietary pattern across bone mass levels is presented in Table 4.

Table 3 Comparison of activity levels and sunlight exposure across different bone mass groups

Item	Osteoporosis	Osteopenia	Normal	χ^2	*P*
Activity				10.994	0.027
Low	10 (6.85%)	31 (21.23%)	12 (8.22%)		
Middle	6 (4.11%)	29 (19.86%)	14 (9.59%)		
High	5 (3.42%)	16 (10.96%)	23 (15.75%)		
Sunshine				11.572	0.021
< 30min	15 (10.27%)	38 (26.03%)	16 (10.96%)		
30-60min	4 (2.74%)	34 (23.29%)	26 (17.81%)		
> 60min	2 (1.37%)	4 (2.74%)	7 (4.79%)		

The chi-square test showed significant differences in bone mass levels among the dietary patterns (χ^2 = 13.775, P = 0.008). Additionally, a strong correlation was observed between dietary patterns and the prevalence of OP (Cramer's V = 0.217, P = 0.008). Further post-hoc analysis, using adjusted standardized residuals, revealed a notable association between the heavy oil and high salt dietary pattern and the OP group. The adjusted standardized residual for this dietary pattern among individuals with OP was 3.6. This version ensures clarity and accuracy, while adhering to the conventions of research writing.

3.4 Comparison of DII and bone mass level

This study analyzed the DII scores of 146 male participants, with an average score of 1.415 ± 4.331. The average DII scores in the OP, osteopenia, and normal bone mass groups were 4.424 ± 5.014, 2.165 ± 3.804, and -1.039 ± 3.546, respectively, showing statistically significant differences (F = 17.228, P < 0.05). The DII is a qualitative measure used to assess the inflammatory potential of dietary structures. Diets were categorized the pro-inflammatory diet group with DII > 0 and the anti-inflammatory diet group with DII < 0. The average DII score in the anti-inflammatory diet group was -3.108 ± 2.384, while that in the pro-inflammatory diet group was 3.992 ± 2.802. A chi-square test revealed significant differences in bone mass levels between the two dietary groups (χ^2 = 19.385, P < 0.001), as detailed in Table 5.

Pearson correlation analysis was conducted to examine the relationship between DII scores and BMD at the lumbar vertebrae (L1-L4), FN, and hip. The results indicated a significant negative correlation between DII scores and BMD at all three sites (P < 0.001). After adjusting for confounding factors such as age, weight, height, and BMI, partial correlation analysis confirmed these findings. The adjusted results showed that dietary inflammation in middle-aged men was negatively correlated with BMD at the following sites: lumbar spine (r = -0.356, P < 0.001), FN (r = -0.292, P < 0.001), and hip (r = -0.352, P < 0.001). These findings emphasize the importance of anti-inflammatory dietary patterns in maintaining bone health and reducing the risk of bone mass loss among middle-aged men.

3.5 Analysis of influencing factors of OP

Univariate analysis of non-dietary factors influencing OP revealed statistically significant associations between smoking history, sunlight exposure, and exercise levels with OP across different bone mass levels (P < 0.05). These factors were subsequently analyzed using binary logistic regression, with bone mass as the dependent variable and the identified factors as independent variables. The results indicated that smoking was a significant risk factor for OP. Smokers were 4.0 times more likely to develop OP compared to non-smokers (OR: 4.008, 95% CI: 1.199-13.398, P < 0.05).

Among dietary influencing factors, individuals adhering to a heavy oil and high salt diet were found to have a significantly increased risk of OP, with the odds being 9.5 times higher compared to those following a vegetable-meat-egg dietary pattern (OR: 9.526, 95% CI: 1.800-50.411, P < 0.05). Furthermore, the pro-inflammatory diet was identified as a substantial risk factor for OP. Individuals following a pro-inflammatory dietary pattern had a 7.7-fold higher risk of developing OP compared to those in the anti-inflammatory diet group (OR: 7.273, 95% CI: 1.444-36.644, P < 0.05), as detailed in Table 6.

These findings underscore the importance of addressing modifiable risk factors, including smoking cessation, increased sunlight exposure, regular exercise, and dietary improvements, in OP prevention strategies.

4 Discussion

This study focuses on the prevalence of OP in males, analyzing the relationship between dietary habits and other influencing factors of OP among individuals aged 50 to 65 in Harbin, a cold region in northeastern Heilongjiang Province, China. The aim is to provide theoretical support for the early diagnosis of OP in men. In this study, the prevalence of OP was 14.38%, with osteopenia accounting for 52.06% and normal bone mass for 33.56%. In comparison, the latest epidemiological survey of OP in China (2018) reported a prevalence of 6.0% for OP and 46.4% for low bone mass in men over 50 years old, and 10.7% for OP in men over 65 years old[9]. These differences may be closely related to the regional characteristics and living habits of Heilongjiang. Located in a cold region, Heilongjiang experiences extremely low winter temperatures, long freezing periods, and limited sunlight exposure.

Table 4 Correlation analysis between dietary pattern and bone mass level

Diet	Osteoporosis		Osteopenia		Normal	
	number of people (*N*)	Constituent ratio (%)	number of people (*N*)	Constituent ratio (%)	number of people (*N*)	Constituent ratio (%)
Vegetable, meat and egg	2 (-2.3)	1.370	26 (0.9)	17.808	17 (0.7)	11.644
Balanced	5 (-1.3)	3.425	31 (1.2)	21.233	17 (-0.3)	11.644
Heavy oil and high salt	14 (3.6)	9.589	19 (-2.1)	13.017	15 (-0.4)	10.274

Figures in brackets are adjusted residuals.

Table 5 Comparison of bone mass levels between the pro-inflammatory diet group and the anti-inflammatory diet group

Bone mass level	Pro-inflammatory diet	Anti-inflammatory diet	χ^2	P
Osteoporosis	19 (13.01%)	2 (1.27%)	19.385	< 0.001
Osteopenia	54 (36.97%)	22 (15.07%)		
Normal	20 (13.70%)	29 (19.86%)		

Table 6 Results of binary logistic regression analysis

Item	β	s.E.	wald χ^2	*P*	OR	95%CI
Smoking History						
No *vs.* Yes	1.388	0.616	5.085	0.024	4.008	1.199, 13.398
Sunshine						
30-60 min *vs.* < 30 min	-0.293	0.655	0.200	0.655	0.746	0.207, 2.694
> 60 min *vs.* < 30 min	0.092	0.717	0.017	0.897	1.097	0.269, 4.469
Activity						
Middle *vs.* Low	-1.323	0.674	3.845	0.050	0.266	0.071, 0.999
High *vs.* Low	-0.749	0.993	0.569	0.451	0.473	0.068, 3.310
Dietary pattern						
Heavy oil and salt diet *vs.* Vegetables, meat and eggs diet	2.254	0.850	7.031	0.008	9.526	1.800, 50.411
Balanced diet *vs.* Vegetables, meat and eggs diet	0.711	0.922	0.594	0.441	2.035	0.334, 12.401
Dietary inflammatory index						
Anti-inflammatory diet *vs.* Pro-inflammatory diet	1.984	0.825	5.784	0.016	7.273	1.444, 36.644

Previous epidemiological studies have shown that living in cold areas, with the associated physiological changes and unhealthy lifestyle behaviors, increases the risk of related chronic diseases, such as hypertension and chronic obstructive pulmonary disease[10-11]. However, limited research has explored the incidence of OP in middle-aged men. While the risk factors for OP and fractures in men are similar to those in women, the prevalence of OP in men should not be underestimated. Early detection and intervention are critical to managing this condition[12]. The distinctive climate of cold regions, characterized by thick winter clothing and reduced outdoor activity, significantly limits sunlight exposure, impairing residents' ability to synthesize vitamin D. Walking on snow and ice during winter also increases the risk of falls. Furthermore, the unique dietary habits in cold regions contribute to the risk of OP. These include high-fat, high-protein, and high-calorie diets; low intake of fresh vegetables and fruits; and high consumption of pickled and dried vegetables[13].

The slightly higher prevalence of male OP observed in this study compared to national statistics highlights the influence of these regional factors. However, as a single-center study with a relatively small sample size, its findings have limitations in representing bone mass across the entire frigid region. Nevertheless, the results reflect a higher prevalence rate in this area, which may be attributed to various risk factors, including climate, sunlight exposure, physical activity, and dietary culture. Future studies should incorporate larger and more diverse sample sizes to improve the generalizability of these findings and provide deeper insights into effective prevention and management strategies for OP in frigid regions.

The results of this study showed no correlation between height, weight, BMI, and bone mass levels across the groups. This lack of significant findings may be attributed to the well-balanced characteristics of the study population, which comprised healthy individuals undergoing physical examinations, with minimal variation in height, weight, and BMI. Previous studies have demonstrated that BMI is an important factor affecting BMD, with a lower BMI associated with an increased risk of OP[14]. Furthermore, obese men have been found to have a lower risk of fracture compared to men with normal weight[15]. However, some studies have observed the opposite, indicating that obesity may increase the risk of OP in elderly men[16]. These conflicting findings suggest uncertainty about the effect of adipose tissue on bone health. Mechanical pressure exerted by skeletal muscle on bones and nutritional factors are critical for increasing bone mass. Future research could benefit from subdividing body composition, such as analyzing lean body mass index and fat body mass index, and exploring their correlations with OP.

This study also investigated the relationship between smoking, alcohol consumption, and BMD. The prevalence of OP among smokers (10.96%) was significantly higher than that among non-smokers (3.42%). Logistic regression analysis confirmed smoking as a risk factor for OP, with smokers being 4.008 times more likely to develop the condition. These findings are consistent with a cross-sectional study of 770 men by Yang *et al.*, which identified smoking as an independent risk factor for male OP in the Han Chinese population[17]. Tobacco contains compounds such as nicotine that increase osteoclast activity, accelerate bone loss, and lower blood estrogen levels, leading to imbalances in calcium and phosphorus regulation that adversely affect bone density[18].

No significant association was observed between alcohol consumption and OP in this study, consistent with the findings of Yang *et al.*[19]. However, earlier studies suggest that alcohol may influence BMD by reducing serum thyroid hormone concentrations and increasing estrogen levels, potentially in a dose-dependent manner[20]. This study did not explore alcohol

consumption in depth, which may have contributed to the lack of findings on this factor.

Sunlight exposure was significantly associated with bone mass levels. The prevalence of OP among individuals with daily sunlight exposure of less than 30 min, 30-60 min, and more than 60 min was 10.27%, 2.74%, and 1.37%, respectively. Vitamin D plays a crucial role in bone cell metabolism by increasing calcium and phosphorus levels in the blood and reducing parathyroid hormone secretion. Most vitamin D in the body is synthesized in the skin from subcutaneous 7-dehydrocholesterol through ultraviolet radiation, with a smaller proportion derived from dietary sources. Adequate sunlight exposure is considered a protective factor for BMD[21].

Studies in Australia have shown that the country's sunshine guidelines (September to April: a few min; May to August: 2-3 h around midday) effectively maintain vitamin D levels during summer but are less effective in winter. This discrepancy is attributed to reduced ultraviolet intensity and limited skin exposure during colder months[22]. Similarly, Heilongjiang's long winters and short summers result in insufficient ultraviolet radiation during winter, even with adequate sunshine. Health education promoting adequate sunlight exposure in summer and dietary vitamin D intake during winter could mitigate this issue.

This study also found that middle-aged men engaged in suboptimal levels of physical activity, with 69.89% of participants reporting low-to-moderate activity levels. Walking was the predominant exercise mode, and work activities were mainly light-intensity. These characteristics, limited activity time, low intensity, and infrequent exercise, are not conducive to maintaining bone mass. The study highlights the need to improve exercise practices among middle-aged men, emphasizing the importance of increasing activity levels, intensity, and diversity to effectively promote and safeguard bone health.

This study reported that three male subjects had a history of fragility fractures, accounting for 2.05% of the total sample. This occurrence did not show a statistically significant relationship with bone mass levels (P = 0.054). Osteoporotic fractures, which occur after minor trauma (*e.g.*, a fall from standing height or lower), represent a severe outcome of OP. A study of healthy men over 50 years old found a significant difference in the prevalence of fragility fractures between the OP group and the non-OP group. In that study, 43.8% of men over the age of 70 had a higher incidence of fragility fractures[23]. It is important to note that fractures are not exclusively associated with OP. However, a history of fragility fractures is considered a clinical high-risk factor for male OP and subsequent osteoporotic fractures[24]. Male patients with a history of hip fractures were found to have a 4.6-fold increased risk of repeat fractures, which is closely associated with increased mortality[12]. A meta-analysis of 55 observational studies focusing solely on male participants, conducted by Drake *et al.*, revealed that risk factors such as excessively low BMI, excessive alcohol consumption, smoking, glucocorticoid use, a history of fractures, and falls within the past 12 months were strongly associated with low BMD and osteoporotic fractures[25]. While this study did not observe statistical significance in fragility fracture prevalence due to the small sample size and limited number of participants with a fracture history, this does not imply that middle-aged men should dismiss the risk of fragility fractures. Such fractures may become significant factors influencing bone health in elderly men in the future.

In addition, this study identified that 10 out of 146 middle-aged men (6.85%) reported a family history of OP or fractures, with one or both parents affected. No statistically significant difference in family history prevalence was observed among the different bone mass groups. While family history is a well-established risk factor for OP in women, its role in male OP remains controversial. The lack of significant findings in this study may be attributed to the small sample size, the limited number of participants with a family history, and the possible lack of awareness of OP among participants and their parents. Additionally, the absence of comprehensive testing and diagnosis in the participants' families could have contributed to the findings. Future research with larger sample sizes and more detailed familial assessments is necessary to clarify the role of family history in male OP.

In this study, dietary intake over the past 12 months was assessed using a dietary frequency questionnaire. Factor analysis identified three main dietary patterns: the "vegetable, meat, and egg dietary pattern", the "vegetarian dietary pattern", and the "heavy oil and high salt dietary pattern". These dietary patterns were found to be associated with different bone mass levels. Individuals with unhealthy bone mass levels were more likely to follow the heavy oil and high salt dietary pattern, characterized by the consumption of snacks, nuts, and oil- and salt-rich condiments.

Previous studies have demonstrated that a high-salt diet negatively affects bone formation by increasing bone resorption relative to bone formation, ultimately reducing bone density[26]. Animal studies have further shown that high-salt diets degrade bone microstructure and decrease bone mass in mice[27]. Additionally, puffed foods and nuts,

which are often high in fat, have been linked to bone loss in experimental mice lacking the low-density lipoprotein receptor gene. Excessive dietary fat, particularly saturated fatty acids found in oils, promotes systemic inflammation, accelerates osteoclast activity, and adversely affects bone health[28]. Most studies have suggested a positive correlation between high dietary protein intake and BMD. Protein-rich diets improve bone quality by increasing insulin-like growth factor-1 (IGF-1), enhancing intestinal calcium absorption, inhibiting parathyroid hormone secretion, and improving muscle strength[29]. Compared to the vegetable-meat-egg dietary pattern, the vegetarian dietary pattern was richer in protein content and included a broader variety of daily food types. This aligns with the vegetarian dietary recommendations in the Dietary Guidelines for Chinese Residents (2022). Interestingly, fruits and dairy products were not included in the main dietary patterns identified through principal component analysis. This exclusion may be due to the low consumption of these foods among the study participants, leading to no significant correlations with bone mass levels. Future research should further explore the role of these food groups in bone health.

The results indicate a significant difference in bone mass levels between the pro-inflammatory diet group and the anti-inflammatory diet group. Correlation analysis between dietary inflammation and BMD of the lumbar spine, FN, and hip revealed a negative association between dietary inflammation and BMD. In this study, more than half of the participants followed diets that potentially promote inflammation, including fried foods and items containing trans fats. This finding aligns with previous large-scale studies conducted in similar regions[30-31]. Research on the relationship between dietary inflammation and OP in middle-aged men remains limited. In cohort studies involving middle-aged and elderly men and women, Kim *et al.* found that individuals with the highest dietary inflammation scores did not show a significant correlation with OP risk in men but demonstrated a correlation with OP risk in women[32]. Conversely, studies by Cervo *et al.*[33] and Mazidi *et al.*[34] suggested that pro-inflammatory diets have adverse effects on bone health in both men and women. A case-control study in China reported that a pro-inflammatory diet, reflected by a higher dietary inflammation index score, was associated with a higher risk of osteoporotic hip fractures in men[35]. These varying perspectives may be partially explained by differences in study design and sample sizes. For example, in Kim's study, the male OP sample size was much smaller than that of females, which could limit the study's findings. Further research is needed to clarify the association between the dietary inflammation index and OP risk in men, particularly in middle-aged populations. Such studies could contribute valuable insights into the role of diet in the prevention and management of male OP.

There are several mechanisms through which a pro-inflammatory diet influences bone health. Consistent consumption of a diet with a high inflammatory index over the long term is likely to elevate systemic inflammation levels. Studies have shown that prolonged high intake of foods rich in saturated fatty acids promotes increased levels of interleukin (IL)-1 and IL-6 in the body[34]. Additionally, Cervo *et al.* found that a pro-inflammatory diet elevates the concentrations of IL-6, IL-7, and tumor necrosis factor-α (TNF-α) in male serum, which is also associated with an increased risk of falls[31]. This study did not measure the levels of IL-6, IL-7, or TNF-α, so a comparative analysis could not be performed. However, this finding suggests a new avenue for further research: exploring the impact of a pro-inflammatory diet on bone mass and its underlying mechanisms.

In clinical observational studies, researchers found that serum IL-6 concentration was positively correlated with BMD of the FN, while TNF-α concentration was positively correlated with BMD of the spine in postmenopausal women. However, elevated serum inflammatory factor levels were not sufficient to accurately predict BMD in individuals with a low risk of OP[34]. This indicates that measuring serum inflammatory factors is not a reliable method for determining OP risk in healthy, low-risk populations, particularly middle-aged individuals. Nevertheless, low-level proinflammatory factors can disrupt bone metabolism, which, over time, may progress into OP. Recent research on the relationship between a pro-inflammatory diet and OP has predominantly focused on postmenopausal women[36]. These studies have identified a correlation between dietary inflammation, OP risk, and osteoporotic fractures in postmenopausal women. However, this association is rarely observed in men. The results of the current study support the hypothesis that a pro-inflammatory diet in middle-aged men is positively associated with an increased risk of OP. Further investigations are needed to elucidate the specific inflammatory pathways involved and their long-term effects on bone health in men.

In terms of influencing factors such as smoking history, sunlight exposure, physical activity, and diet, the current study demonstrated that smoking history is an independent risk factor for male OP. Additionally, the heavy oil and high salt dietary pattern and the pro-inflammatory diet were positively associated with the risk of OP, as determined through binary logistic regression analysis. These findings are consistent with previous studies conducted in different countries[29,37]. For example, the traditional Mediterranean diet, rich in vegetables, fruits, fish, and seafood, has been shown to have a protective

effect on BMD and reduce fracture risk[29]. Conversely, Western dietary patterns, including snacks, takeout foods, soft drinks, high-fat dairy products, and processed meats, have been linked to low bone density[37].

The high-salt dietary pattern, characterized by heavy oil, snacks, and oil- and salt-rich condiments, is abundant in nutrients known to promote inflammation, such as carbohydrates, cholesterol, fat, trans fatty acids, and saturated fatty acids. This suggests that individuals following this dietary pattern may experience accelerated bone loss and an increased risk of OP through multiple mechanisms. It is important to note that diet is not merely a combination of individual nutrients but a complex interplay of multiple elements that require comprehensive analysis. Dietary habits vary significantly across regions and cultures. Differences in dietary patterns are observed not only between countries, but also between the northern and southern regions of China. This study focused on dietary patterns extracted from dietary questionnaire surveys of middle-aged men in alpine areas, representing the dietary habits of this specific population. The findings provide a theoretical foundation for bone health dietary guidance tailored to middle-aged men in this region.

There are several limitations to this study. Due to objective factors, the research sample size was relatively small and only partially representative of the dietary structure of individuals in this area. A larger sample study is needed to further validate the current findings regarding the relationship between diet and bone mass. The sample size of this study was 146, with a significance level of 0.05 and an effect size controlled within a reasonable range based on previous research. Consequently, the statistical power of this study reached 80%, indicating that the findings have a certain degree of credibility. Additionally, when collecting dietary data, participants were asked to recall their dietary habits over the past year. This reliance on self-reported data introduces potential memory bias, which could affect the frequency and accuracy of dietary intake reporting. Future research should address these limitations to provide more robust and generalizable conclusions.

This study has several limitations. The small sample size, influenced by objective factors, only represents the dietary structure of a subset of individuals in this region. Larger sample studies are needed to validate the current findings regarding the relationship between diet and bone mass. The sample size of this study was 146, with a significance level of 0.05 and an effect size controlled within a reasonable range based on previous research. Consequently, the statistical power of this study reached 80%, indicating that the findings have a certain degree of credibility. Additionally, the dietary data were collected through self-reported recall of participants' dietary habits over the past year. This reliance on memory introduces potential bias, which may affect the accuracy and frequency of reported dietary intake. Future research should aim to address these limitations by incorporating larger, more diverse samples and using more precise dietary assessment methods.

5 Conclusion

In this study, the prevalence of OP in men was 14.38%, with osteopenia accounting for 52.06%. The relatively high prevalence of OP in men underscores the need for early prevention and health guidance. Non-dietary factors, including sunshine exposure, exercise, and smoking history, were found to be associated with OP. It is recommended that general practitioners emphasize these risk factors in health guidance, advising individuals to quit smoking, engage in regular physical activity, and increase sunlight exposure. Moreover, education on the risks associated with dietary factors, particularly the heavy oil and high salt diet prevalent in the pro-inflammatory diet group, is essential. These findings provide theoretical support for grassroots dietary guidance that general practitioners can implement to improve bone health in middle-aged men. An unhealthy lifestyle and pro-inflammatory diet may influence bone metabolism by altering the composition of intestinal flora, laying a foundation for further experimental research into the mechanisms of dietary impact on bone health.

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Research ethics

This study was conducted in accordance with the Helsinki Declaration and was approved by the Ethics Committee of the Second Affiliated Hospital of Harbin Medical University (KY2022-209).

Informed consent

All participants provided written informed consent prior to their inclusion in the study.

Author contributions

Conceptualization: Meng J; Statistical analysis: Miao X H, Xu C;

Manuscript writing and revision: Zhang Y Q, Miao X H, Zeng Y; Experiment implementation and data collection: Miao X H, Guo M, Nie Y Z; Critical revision of the manuscript for important intellectual content: Meng J, Jiang L H. All authors approved the final version of this manuscript.

Use of Large Language Models, AI and Machine Learning Tools

No large language models, AI or machine learning tool was used for any part of the present study.

Conflict of interest

The authors declare no competing interests.

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Data availability

All data used during the study are available from the corresponding author by request.

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