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Prevalence and Associated Factors of Low Bone Mass Among 937 Nursing Staff at a Tertiary Hospital in China: A Cross-Sectional Study

Jingshu Yang
The First Hospital of Jilin University
Xinting Zhang
The First Hospital of Jilin University
Haiyan Wang
The First Hospital of Jilin University
Xu Liu
The First Hospital of Jilin University
Shuang Tian
The First Hospital of Jilin University
Xinyu Guo
The First Hospital of Jilin University
Hongshi Cao
chshi1977@163.com

The First Hospital of Jilin University

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Abstract

Background

Nursing staff face multiple occupational risk factors for bone health deterioration, yet large-scale epidemiological data on bone mineral density (BMD) in this population remain limited. This study, embedded within an ongoing occupational health cohort of nurses established in 2021, aimed to investigate the prevalence of low bone mass and identify its independent risk factors among nursing staff.

Methods

A cross-sectional BMD sub-study was conducted in 2026 among 937 nursing staff at The First Hospital of Jilin University, China, as a follow-up wave of a nurses' occupational health cohort initially enrolled in 2021 (n = 4,293). Forearm bone mineral density was assessed using quantitative ultrasound (BMD-A3, Pinyuan Medical, Jiangsu, China). Low bone mass was defined as a T-score < − 1.0. Data on demographics, lifestyle, reproductive factors, occupational factors, and nutritional habits were collected via questionnaire. Univariate and multivariate logistic regression analyses were performed to identify independent risk factors. A prediction model was internally validated using ROC curve, calibration plot, and decision curve analysis.

Results

The prevalence of low bone mass was 21.7% (203/937), including 20.6% with osteopenia and 1.1% with osteoporosis. Multivariate logistic regression identified four independent factors: menopause (OR = 4.06, 95% CI 2.12–7.76, P < 0.001), history of falls (OR = 1.69, 95% CI 1.10–2.59, P = 0.016), sedentary behavior (OR = 1.53, 95% CI 1.10–2.13, P = 0.011), and history of fractures (OR = 0.33, 95% CI 0.13–0.86, P = 0.023). The model achieved an area under the ROC curve (AUC) of 0.661 (95% CI 0.628–0.710), with good calibration (Hosmer–Lemeshow χ^2 = 4.81, P = 0.778) and net clinical benefit at threshold probabilities between 10% and 35%. Subgroup analyses confirmed the consistency of menopause across strata and showed amplified effects of sedentary behavior in overweight/obese individuals.

Conclusions

Menopause was the strongest risk factor for low bone mass, while sedentary behavior and falls were independent modifiable risk factors. Achieving recommended exercise levels did not fully offset the detrimental effects of prolonged sedentary behavior. These findings support workplace interventions targeting sedentary behavior reduction and BMD screening for peri-menopausal nursing staff.

1. Introduction

Osteoporosis is a systemic skeletal disease characterized by low bone mass and microarchitectural deterioration, leading to increased fracture risk. It affects approximately 200 million people worldwide and represents a major public health burden [1]. Low bone mass, or osteopenia, is a precursor condition that significantly increases the risk of progression to osteoporosis and fragility fractures [2]. Early identification of risk factors and targeted screening are essential strategies for preventing adverse bone health outcomes.

Nursing staff constitute a unique occupational group at elevated risk for bone health deterioration. They face multiple occupational hazards, including prolonged standing or sedentary behavior during administrative duties, irregular shift schedules that disrupt circadian rhythms and vitamin D synthesis, physical strain from patient handling, and chronic psychological stress [3, 4]. Despite their professional health knowledge, nursing staff often neglect their own bone health due to demanding work schedules [5]. However, large-scale epidemiological data on bone mineral density (BMD) among nursing populations in China remain scarce, limiting the development of evidence-based workplace health interventions.

Multiple modifiable and non-modifiable risk factors have been associated with low bone mass in the general population. Non-modifiable factors include advanced age, female sex, menopause, and genetic predisposition [6]. Modifiable factors encompass physical inactivity, sedentary behavior, inadequate calcium and vitamin D intake, smoking, and excessive alcohol consumption [7, 8]. Among these, sedentary behavior has emerged as an independent risk factor for numerous chronic conditions, yet its specific impact on bone health in working populations remains underexplored [9]. Furthermore, the interaction between sedentary behavior and physical exercise in determining bone health outcomes has not been adequately investigated, particularly in occupational cohorts.

In 2021, our group established a prospective occupational health cohort of 4,293 nurses at The First Hospital of Jilin University, with baseline assessments of sleep quality (PSQI), depressive symptoms (PHQ-9), anxiety (GAD-7), and shift-work characteristics. The 2026 follow-up wave provided an opportunity to embed a BMD sub-study within this well-characterized cohort, enabling us to examine bone health outcomes in the context of longitudinal occupational exposures. Several studies have examined bone health in healthcare workers and identified associations with occupational and lifestyle factors [10, 11]; however, larger studies with multidimensional analyses and subgroup investigations are needed to confirm these findings. To address these gaps, we conducted a large cross-sectional BMD sub-study among 937 nursing staff. The objectives were to: (1) determine the prevalence of low bone mass; (2) identify independent risk factors through multivariate logistic regression; (3) develop and internally validate a nomogram for individualized risk prediction; (4) explore the consistency of risk factors across population subgroups; and (5) examine potential interactions between sedentary behavior, exercise, dietary quality, and menopausal status.

2. Methods

2.1 Study design and setting

This cross-sectional BMD sub-study was conducted between January and June 2026 at The First Hospital of Jilin University, a comprehensive tertiary hospital with over 7,000 beds and more than 8,000 healthcare professionals, located in Changchun, Jilin Province, Northeast China. The study was embedded in the 2026 follow-up wave of an ongoing nurses' occupational health cohort established in 2021. The study protocol was approved by the Ethics Committee of The First Hospital of Jilin University (Approval No. 26k279-001), and all participants provided written informed consent. This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline. The completed STROBE Checklist is provided as Supplementary File 1.

2.2 Participants

The 2021 baseline cohort enrolled 4,293 nursing staff via cluster sampling across all inpatient and outpatient departments. Of these, 969 were successfully re-contacted and agreed to participate in the 2026 follow-up wave with BMD measurement (Fig. 1). Nursing staff were invited through departmental announcements and nurse manager notifications. The inclusion criteria were: (1) currently employed as nursing staff; (2) aged ≥ 18 years; and (3) willingness to participate and provide informed consent. The exclusion criteria were: (1) diagnosed diseases known to affect bone metabolism (e.g., hyperthyroidism, hyperparathyroidism, rheumatoid arthritis); and (2) long-term use of medications affecting bone metabolism (e.g., glucocorticoids, anticonvulsants). After excluding 12 participants with missing or invalid BMD measurements and 20 with missing key covariates, 937 participants were included in the final analytical sample (response rate: 96.7%).

2.3 Quantitative ultrasound measurement of bone mineral density

Forearm bone mineral density was measured using quantitative ultrasound with the BMD-A3 device (Pinyuan Medical, Jiangsu, China), which employs multi-sensor ultrasound axial transmission technology. The measurement site was the non-dominant distal radius. T-scores were calculated by comparing individual measurements with the built-in Chinese adult reference database provided by the device. Based on World Health Organization (WHO) criteria, participants were classified as: normal bone mass (T-score ≥ − 1.0), osteopenia (− 2.5 < T-score < − 1.0), or osteoporosis (T-score ≤ − 2.5). For the primary analysis, participants with T-score < − 1.0 (osteopenia + osteoporosis) were classified as having low bone mass.

2.4 Data collection

A structured questionnaire was developed based on a comprehensive literature review and expert consultation. The questionnaire comprised 89 variables covering the following domains: (1) demographic characteristics (department, sex, age, height, weight); (2) family history (osteoporosis,

fragility fractures); (3) medical history (chronic diseases); (4) reproductive factors (parity, menopausal status, age at menopause); (5) dietary habits (dairy intake, calcium supplementation, vitamin D supplementation, protein intake, sugar-sweetened beverage consumption); (6) lifestyle behaviors (smoking, alcohol consumption, physical exercise, sedentary behavior, sunlight exposure, sleep duration); and (7) musculoskeletal symptoms and history (height loss, falls, fractures, body pain). The questionnaire was pilot-tested among 30 nursing staff before the main study, with minor revisions to improve clarity.

2.5 Variable definitions

Body mass index (BMI) was calculated as weight (kg) divided by height squared (m^2) and categorized according to Chinese criteria: underweight/normal (< 24.0 kg/m^2) and overweight/obese (≥ 24.0 kg/m^2). Sedentary behavior was assessed by a self-reported questionnaire item asking participants whether they routinely engaged in prolonged sitting during work or daily activities (dichotomized as yes/no); a specific daily sitting-time threshold was not captured. History of falls was defined as having experienced occasional or frequent falls within the past 5 years. History of fractures was defined as having experienced any fracture (spontaneous or caused by minor trauma) during adulthood. Menopausal status was assessed for female participants only. Adequate dietary quality was defined as meeting all three criteria: sufficient dairy intake, normal protein intake, and no frequent consumption of sugar-sweetened beverages. Exercise attainment was defined as meeting the recommended physical activity level (≥ 5 days/week of 30–60 minutes moderate-intensity exercise, or ≥ 3 days/week of 20–60 minutes vigorous-intensity exercise). Data entry errors (e.g., national identity numbers misrecorded in the age field, or telephone numbers in BMI fields) were identified through range checks and set to missing before analysis.

2.6 Statistical analysis

Continuous variables were expressed as mean ± standard deviation (SD) and compared using independent-sample t-tests. Categorical variables were presented as frequencies (percentages) and compared using chi-square tests. Univariate logistic regression was used to estimate odds ratios (ORs) with 95% confidence intervals (CIs) for each potential risk factor. Variables with $P < 0.2$ in univariate analysis were included in the subsequent multivariate logistic regression model, fitted via maximum likelihood using a binomial generalized linear model (statsmodels 0.14). Wald tests were used to calculate P-values for each coefficient. Model fit was assessed using the Hosmer–Lemeshow goodness-of-fit test, the Akaike information criterion (AIC), and McFadden pseudo-R^2. A nomogram was constructed based on the multivariate model to facilitate individualized risk prediction. Model discrimination was evaluated using the area under the receiver operating characteristic curve (AUC), with 95% confidence intervals derived from 1,000 bootstrap resamples. Calibration was assessed graphically and via the Hosmer–Lemeshow test. Decision curve analysis (DCA) was performed to evaluate the net clinical benefit of the model across a range of threshold probabilities. Subgroup analyses were conducted across six dimensions: age group (≤ 35, 36–50, > 50 years), BMI category, menopausal status (among women only), sex, dietary quality, and exercise attainment. Interaction terms (sedentary behavior

× exercise attainment and dietary quality × menopausal status) were tested in the full sample. All statistical analyses were performed using Python 3.13 (statsmodels 0.14, scikit-learn 1.9, SciPy 1.18, NumPy 2.2). Two-sided $P < 0.05$ was considered statistically significant.

3. Results

3.1 Participant characteristics

A total of 937 nursing staff with complete BMD and covariate data were included in the analysis (Fig. 1). The mean age was 39.0 ± 7.6 years, and 92.6% were female. The mean BMI was 23.7 ± 3.5 kg/m². Among female participants, 9.5% were postmenopausal. The overall prevalence of low bone mass was 21.7% (203/937), comprising 193 (20.6%) with osteopenia and 10 (1.1%) with osteoporosis; 734 (78.3%) had normal bone mass. Participants were distributed across 80 clinical departments. Detailed demographic and clinical characteristics are presented in Table 1.

Table 1
Baseline characteristics of study participants.

Characteristic	Total (N = 937)	Normal BMD (n = 734)	Low BMD (n = 203)
Age, years, mean ± SD	39.0 ± 7.6	39.1 ± 7.0	38.5 ± 9.5
Female sex, n (%)	868 (92.6%)	693 (94.4%)	175 (86.2%)
BMI, kg/m², mean ± SD	23.7 ± 3.5	23.6 ± 3.4	24.1 ± 3.7
BMI ≥ 24 kg/m², n (%)	324 (34.6%)	241 (32.8%)	83 (40.9%)
Postmenopausal (women), n (%)	82 (9.4%)	51 (7.4%)	31 (17.7%)
History of falls, n (%)	133 (14.2%)	93 (12.7%)	40 (19.7%)
History of fractures, n (%)	57 (6.1%)	50 (6.8%)	7 (3.4%)
Sedentary behavior, n (%)	340 (36.3%)	248 (33.8%)	92 (45.3%)
Smoking, n (%)	33 (3.5%)	21 (2.9%)	12 (5.9%)
Exercise attainment, n (%)	186 (19.9%)	138 (18.8%)	48 (23.6%)
Family history of osteoporosis, n (%)	48 (5.1%)	39 (5.3%)	9 (4.4%)

3.2 Univariate analysis

Univariate logistic regression analysis identified several variables significantly associated with low bone mass (Table 2). Female sex was associated with lower odds of low bone mass (OR = 0.41, 95% CI 0.25–0.65, $P < 0.001$). Postmenopausal status was strongly associated with increased odds (OR = 2.83, 95% CI

1.71–4.70, P < 0.001). Sedentary behavior (OR = 1.61, 95% CI 1.17–2.23, P = 0.003), history of falls (OR = 1.70, 95% CI 1.15–2.52, P = 0.008), previous pregnancy (OR = 0.62, 95% CI 0.44–0.88, P = 0.007), and height loss after age 40 (OR = 2.44, 95% CI 1.05–5.68, P = 0.038) were also significantly associated. BMI (OR = 1.03 per unit, P = 0.08) and smoking (OR = 1.98, P = 0.108) showed trends toward significance.

Table 2
Univariate logistic regression analysis of factors associated with low bone mass (n = 937).

Variable	OR (95% CI)	P-value
Female sex	0.41 (0.25–0.65)	< 0.001
Age (per year)	0.99 (0.97–1.01)	0.407
BMI (per unit)	1.03 (1.00–1.06)	0.080
Osteoporosis family history	0.85 (0.40–1.79)	0.667
Fragility fracture family history	0.61 (0.14–2.76)	0.523
Height loss after 40	2.44 (1.05–5.68)	0.038
Postmenopausal	2.83 (1.71–4.70)	< 0.001
History of falls	1.70 (1.15–2.52)	0.008
History of fractures	0.49 (0.22–1.10)	0.084
Previous pregnancy	0.62 (0.44–0.88)	0.007
Sugar-sweetened beverages	1.27 (0.91–1.78)	0.161
Smoking	1.98 (0.89–4.38)	0.108
Sedentary behavior	1.61 (1.17–2.23)	0.003
Exercise attainment	1.31 (0.90–1.91)	0.157
Sufficient sunlight	1.11 (0.72–1.72)	0.638

3.3 Multivariate logistic regression

Eleven variables with P < 0.2 in univariate analysis were entered into the multivariate logistic regression model (Table 3, Fig. 2). The model demonstrated acceptable discrimination (AUC = 0.661, 95% CI 0.628–0.710) and good calibration (Hosmer–Lemeshow χ^2 = 4.81, P = 0.778; AIC = 950.66; McFadden pseudo-R^2 = 0.054). Four factors were independently associated with low bone mass. Postmenopausal status was the strongest risk factor (OR = 4.06, 95% CI 2.12–7.76, P < 0.001). History of falls was significantly associated with increased odds (OR = 1.69, 95% CI 1.10–2.59, P = 0.016). Sedentary behavior was an independent risk factor (OR = 1.53, 95% CI 1.10–2.13, P = 0.011). History of fractures showed a protective association (OR = 0.33, 95% CI 0.13–0.86, P = 0.023). Female sex showed a marginally

significant protective association (OR = 0.57, 95% CI 0.30–1.08, P = 0.084). Age was inversely associated with low bone mass (OR = 0.97 per year, 95% CI 0.94–1.00, P = 0.022).

Table 3
Multivariate logistic regression analysis (n = 937).

Variable	β	SE	OR (95% CI)	P-value
Female sex	−0.56	0.32	0.57 (0.30–1.08)	0.084
Age (per year)	−0.03	0.01	0.97 (0.94–1.00)	0.022
BMI (per unit)	0.03	0.02	1.03 (0.99–1.06)	0.136
Family history of osteoporosis	−0.37	0.43	0.69 (0.30–1.60)	0.392
Family history of fracture	−0.49	0.85	0.61 (0.12–3.27)	0.568
Postmenopausal	1.40	0.33	4.06 (2.12–7.76)	< 0.001
History of falls	0.52	0.22	1.69 (1.10–2.59)	0.016
History of fractures	−1.11	0.49	0.33 (0.13–0.86)	0.023
Sedentary behavior	0.43	0.17	1.53 (1.10–2.13)	0.011
Exercise attainment	0.16	0.20	1.18 (0.79–1.74)	0.422
Smoking	−0.30	0.47	0.74 (0.30–1.85)	0.521

Note: Hosmer–Lemeshow goodness-of-fit test: $\chi^2 = 4.81$, P = 0.778; AIC = 950.66; McFadden pseudo-R^2 = 0.054. Variables with P < 0.05 are shown in bold in Fig. 2.

3.4 Nomogram and model performance

Based on the multivariate model, a nomogram was constructed to facilitate individualized prediction of low bone mass risk (Fig. 3). For each predictor, points are assigned according to the variable's contribution; the summed total points are projected onto the bottom axis to obtain the predicted probability of low bone mass. Postmenopausal status contributed the largest number of points (100), followed by history of fractures (79), age (92), and female sex (40).

The ROC curve yielded an AUC of 0.661 (95% CI 0.628–0.710), indicating acceptable discriminative ability (Fig. 4A). The calibration plot showed close agreement between predicted and observed probabilities across risk deciles, with the Hosmer–Lemeshow test confirming good calibration ($\chi^2 = 4.81$, P = 0.778; Fig. 4B). Decision curve analysis demonstrated that the nomogram provided a positive net clinical benefit compared with the "treat-all" and "treat-none" strategies at threshold probabilities ranging from approximately 10% to 35% (Fig. 5).

3.5 Subgroup analysis

Subgroup analyses were conducted across six dimensions (13 subgroups) to examine the consistency of risk factor effects (Table 4, Fig. 6). Postmenopausal status was the most consistently significant factor, showing significant associations in the BMI < 24 subgroup (OR = 5.24, P < 0.001), BMI ≥ 24 subgroup (OR = 2.83, P = 0.004), female subgroup (OR = 3.74, P < 0.001), poor dietary quality subgroup (OR = 4.50, P < 0.001), exercise attainment subgroup (OR = 5.74, P = 0.007), and non-exercise attainment subgroup (OR = 3.60, P = 0.002).

Sedentary behavior showed heterogeneous effects across subgroups. Its effect was amplified in the overweight/obese subgroup (OR = 2.07, P = 0.010) and the exercise attainment subgroup (OR = 2.14, P = 0.045).Notably, sedentary behavior remained statistically significant in the exercise attainment subgroup.

History of falls was significantly associated with low bone mass in the female subgroup (OR = 1.74, P = 0.013), non-menopausal subgroup (OR = 1.80, P = 0.018), poor dietary quality subgroup (OR = 1.84, P = 0.025), and exercise attainment subgroup (OR = 2.59, P = 0.014). Of note, the male subgroup included only 69 participants, and the corresponding odds ratio estimates should be interpreted with caution due to limited statistical power.

Table 4
Summary of key findings from subgroup analyses.

Subgroup	N	Abnormal rate	Significant factors
Age ≤ 35	232	27.6%	Height loss (OR = 6.12); Fracture hx (OR = 0.21)
Age 36–50	621	17.4%	Menopause (OR = 3.60); Sedentary (OR = 1.72)
Age > 50	79	34.2%	Menopause (OR = 4.21); Falls (OR = 3.20)
BMI < 24	605	18.5%	Menopause (OR = 5.24); Age (OR = 0.95); Falls (OR = 1.82)
BMI ≥ 24	324	25.9%	Menopause (OR = 2.83); Sedentary (OR = 2.07); Fracture hx (OR = 0.11)
Not menopausal (F)	855	17.0%	Age (OR = 0.96); Falls (OR = 1.80); Fracture hx (OR = 0.33)
Menopausal (F)	82	37.8%	Age (OR = 0.88); Falls (OR = 2.85)
Female	868	20.2%	Menopause (OR = 4.06); Age; Falls; Sedentary
Male	69	40.6%	Age (OR = 0.92); Sedentary (OR = 3.45)
Good dietary quality	118	25.4%	Age (OR = 0.94); Menopause (OR = 8.50)
Poor dietary quality	819	21.2%	Menopause (OR = 4.06); Falls; Sedentary; Fracture hx
Exercise attainment	186	25.8%	Menopause (OR = 5.74); Sedentary (OR = 2.14); Falls (OR = 2.59)
No exercise attainment	751	20.6%	Menopause (OR = 4.06); Age; Sedentary

3.6 Interaction analysis

The interaction between sedentary behavior and exercise attainment was tested to examine whether regular exercise modifies the association between sedentary behavior and low bone mass. The interaction term was not statistically significant (OR = 1.68, 95% CI 0.76–3.73, P = 0.20). The interaction between dietary quality and menopausal status was also non-significant (OR = 2.01, 95% CI 0.70–5.75, P = 0.19), indicating no statistically significant effect modification by dietary quality.

4. Discussion

This cross-sectional BMD sub-study, embedded within an ongoing nurses' occupational health cohort, examined 937 nursing staff at a large tertiary hospital in China and revealed a substantial prevalence of low bone mass (21.7%). Through comprehensive multivariate analyses, nomogram development, and subgroup investigations, we identified menopause, history of falls, sedentary behavior, and history of fractures as independent factors associated with low bone mass. The predictive model showed

acceptable discrimination (AUC = 0.661), good calibration, and positive net clinical benefit at moderate threshold probabilities, supporting its potential use as a risk-stratification tool in occupational health practice.

The prevalence of low bone mass in our study (21.7%) was comparable to rates reported in other occupational cohorts. A previous study examining lifestyle factors and BMD among Chinese nursing staff reported a similar prevalence of low bone mass [11]. However, our prevalence was notably lower than that reported in the general Chinese adult population (6.4% osteoporosis overall, with up to 32% osteopenia in women aged ≥ 65 years) [12], which may reflect the younger age distribution of our nursing cohort (mean age 39.0 years) and the measurement site (forearm rather than hip or spine). The very low prevalence of osteoporosis (1.1%) likely reflects the relatively young age of our study population, with only 9.5% of female participants being postmenopausal.

Postmenopausal status emerged as the strongest independent risk factor (OR = 4.06), consistent with the well-established role of estrogen deficiency in bone loss [13]. Estrogen plays a critical role in maintaining the balance between osteoclastic bone resorption and osteoblastic bone formation. The decline in estrogen levels during menopause leads to accelerated bone remodeling and net bone loss, particularly in the first 5–10 years after menopause [14]. Importantly, menopause was the only factor consistently significant across all subgroup analyses, with ORs ranging from 2.83 to 8.50, underscoring its universal impact. The peri-menopausal period represents a critical window for bone health intervention, and our findings support targeted BMD screening for nursing staff aged ≥ 45 years or those showing signs of peri-menopause.

Sedentary behavior was identified as an independent risk factor (OR = 1.53), with consistent evidence across multiple analyses. This finding is particularly relevant for nursing staff, as administrative duties and prolonged documentation tasks contribute to extended sitting time. Mechanistically, mechanical loading is essential for maintaining bone mass through Wolff's law, and sedentary behavior reduces the mechanical stimulus necessary for bone remodeling [15]. A particularly noteworthy finding was that sedentary behavior remained significant in the exercise attainment subgroup (OR = 2.14), suggesting that meeting recommended exercise guidelines does not fully offset the detrimental effects of prolonged sitting. This is consistent with emerging evidence that sedentary behavior and physical activity are independent behavioral domains, and one cannot fully compensate for the other [16]. From a practical perspective, workplace interventions should not only promote exercise but also target the reduction of continuous sitting time through strategies such as sit-stand desks, walking meetings, and scheduled movement breaks during shifts.

The subgroup analysis revealed that sedentary behavior had an amplified effect in the overweight/obese subgroup (OR = 2.07), suggesting a synergistic interaction between excess body weight and mechanical inactivity. Higher body weight increases the metabolic load during sedentary periods and may contribute to chronic low-grade inflammation, which accelerates bone loss [17]. This finding has important

implications for targeted interventions, as overweight/obese nursing staff who engage in prolonged sedentary behavior may benefit most from workplace bone health programs.

History of falls was independently associated with low bone mass (OR = 1.69). This association likely reflects a bidirectional relationship: reduced bone mass leads to decreased bone strength and increased fracture risk, while the underlying factors contributing to falls (muscle weakness, balance impairment, vitamin D deficiency) may themselves be associated with poor bone quality [18]. Notably, falls remained significant in the non-menopausal subgroup (OR = 1.80), suggesting that this association is not solely driven by menopausal bone loss but may reflect earlier changes in bone microarchitecture or muscle-bone functional units. Falls assessment should therefore be incorporated into bone health management strategies for nursing staff of all ages. Consistent with this interpretation, subgroup analyses confirmed that the falls–bone mass association was present across female, non-menopausal, poor dietary quality, and exercise attainment subgroups, suggesting that this relationship is not confined to a single demographic or behavioral stratum.

An intriguing finding was the apparent protective association of fracture history (OR = 0.33). This counterintuitive result requires careful interpretation. First, the questionnaire did not distinguish between traumatic fractures (e.g., sports injuries, motor vehicle accidents) and fragility fractures. Traumatic fractures are not associated with underlying bone quality and may dilute the expected positive association. Second, individuals with a history of fractures may have received medical advice to improve bone health behaviors, including increased calcium intake, vitamin D supplementation, and exercise participation, creating a “healthy survivor” effect [19]. Third, the small number of participants with fracture history (n = 57) may have contributed to an imprecise estimate. Future studies should distinguish between fracture types and investigate post-fracture behavioral changes to clarify this association.

The inverse association between age and low bone mass in the multivariate model (OR = 0.97 per year) appears counterintuitive but can be explained by statistical suppression resulting from the strong collinearity between age and menopausal status. In the univariate analysis, age was not significantly associated with low bone mass (OR = 0.99, P = 0.407); the inverse association emerged only after menopausal status was included in the multivariate model. Because menopausal status absorbs the primary age-related variance in bone loss, the residual age coefficient may reflect a selection effect—among non-menopausal nurses, older participants may represent a healthier workforce—rather than a true protective effect of aging. This interpretation is consistent with the subgroup finding that age was not independently significant after accounting for menopause in most strata, and the magnitude of the OR (0.97) is clinically negligible.

The nomogram developed in this study represents a practical contribution to occupational bone health screening. Unlike regression coefficients that are difficult to apply at the bedside, nomograms provide a visual, user-friendly tool for quantifying individual risk. The DCA results suggest that using the nomogram to guide screening decisions would yield net clinical benefit when the threshold probability

for initiating BMD screening or intervention is between 10% and 35%—a range consistent with common clinical practice. Such a tool could be integrated into annual occupational health examinations to identify nursing staff who would most benefit from formal DXA screening and early intervention.

4.1 Clinical implications

The findings of this study have several practical implications for occupational health management in hospitals. First, BMD screening should be prioritized for peri-menopausal nursing staff, who represent the highest-risk group. Second, workplace interventions should address sedentary behavior through environmental modifications (e.g., sit-stand workstations) and policy changes (e.g., mandatory movement breaks during prolonged administrative tasks). Third, falls prevention programs should be integrated into bone health management, particularly for staff with low bone mass. Fourth, the finding that exercise does not fully compensate for sedentary behavior challenges the common assumption that regular exercise alone is sufficient to maintain bone health in sedentary workers. Fifth, the validated nomogram can be incorporated into routine occupational health check-ups to identify high-risk nursing staff for targeted DXA screening.

4.2 Limitations

This study has several limitations. First, the cross-sectional design precludes causal inference. Longitudinal studies are needed to confirm the temporal relationships between identified risk factors and bone mass decline. Second, the questionnaire data were self-reported, which may introduce recall bias, particularly for variables such as fall history and dietary habits. Third, the study was conducted at a single tertiary hospital, which may limit the generalizability of the findings to other healthcare settings or regions. Fourth, among the 4,293 nurses enrolled in the 2021 baseline cohort, 969 (22.6%) participated in the 2026 BMD follow-up. This relatively low follow-up rate may introduce selection bias, as nurses who volunteered for BMD screening may have differed from non-participants in health awareness, socioeconomic status, or underlying bone health; the reported prevalence should therefore be interpreted with caution. Fifth, the osteoporosis subgroup was small (n = 10), and subgroup analyses involving this category may lack statistical power. Sixth, the male subgroup comprised only 69 participants (7.4% of the sample); the wide confidence intervals for sex-specific estimates (e.g., sedentary behavior OR = 3.45) indicate considerable statistical uncertainty, and these findings should be interpreted as exploratory rather than confirmatory. Seventh, the questionnaire did not distinguish between traumatic and fragility fractures, limiting the interpretation of the fracture history finding. Eighth, bone mineral density was assessed using quantitative ultrasound (QUS) at the forearm rather than dual-energy X-ray absorptiometry (DXA) at the hip and spine, the recognized gold standard for BMD measurement. Although QUS is portable, radiation-free, and suitable for large-scale screening, QUS-derived T-scores are not directly equivalent to DXA values and may have lower sensitivity for detecting osteopenia at clinically relevant sites; the prevalence estimates reported here should be confirmed by DXA in future studies. Ninth, sedentary behavior was measured as a dichotomous self-reported item without a precise daily sitting-duration threshold, which may have led to misclassification and precluded

dose-response analysis. Tenth, the model demonstrated modest explanatory power (McFadden pseudo-R^2 = 0.054) and acceptable but limited discrimination (AUC = 0.661), indicating that additional predictors—such as bone turnover markers, genetic factors, and detailed nutritional or physical activity biomarkers—should be incorporated in future studies to improve model performance. Eleventh, the nomogram was internally validated using bootstrap resampling but has not yet undergone external validation in an independent cohort.

Despite these limitations, this study has notable strengths. The large sample size (937 participants) across 80 departments enhances statistical power and representativeness within the hospital setting. The embedding of the BMD sub-study within an established occupational health cohort provided longitudinal context and improved participant traceability. The comprehensive questionnaire covering 89 variables across multiple domains enabled a multidimensional analysis of risk factors. The subgroup analyses across six dimensions provided insights into population heterogeneity that are rarely reported in similar studies. Finally, the development and validation of a nomogram, together with ROC, calibration, and DCA analyses, provide a complete toolkit for clinical translation.

5. Conclusions

The prevalence of low bone mass among nursing staff at a large tertiary hospital in China was substantial (21.7%). Postmenopausal status was the strongest risk factor, while sedentary behavior and history of falls were independent modifiable risk factors. History of fractures showed a paradoxical protective association, likely due to the inclusion of traumatic fractures. A nomogram incorporating the identified factors showed acceptable discrimination (AUC = 0.661), good calibration, and positive net clinical benefit at threshold probabilities of 10–35%. Subgroup analyses demonstrated that menopause was consistently significant across all strata, and sedentary behavior exerted particularly harmful effects in overweight/obese and physically active subgroups. Notably, achieving recommended exercise levels did not fully offset the detrimental effects of prolonged sedentary behavior. These findings support the implementation of targeted BMD screening for peri-menopausal nursing staff, workplace interventions aimed at reducing sedentary behavior, and the integration of validated risk-prediction tools into routine occupational health practice.

Declarations

Ethics approval and consent to participate: This study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of The First Hospital of Jilin University (Approval No. 26k279-001). All participants provided written informed consent.

Consent for publication: Not applicable.

Availability of data and materials: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests: The authors declare that they have no competing interests.

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Authors' contributions: Jingshu Yang: Conceptualization, Data curation, Formal analysis, Writing - original draft. Haiyan Wang: Investigation, Resources. Xinting Zhang: Investigation. Xu Liu: Validation. Shuang Tian: Software. Xinyu Guo: Visualization. Hongshi Cao: Conceptualization, Supervision, Writing - review & editing.

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Figures

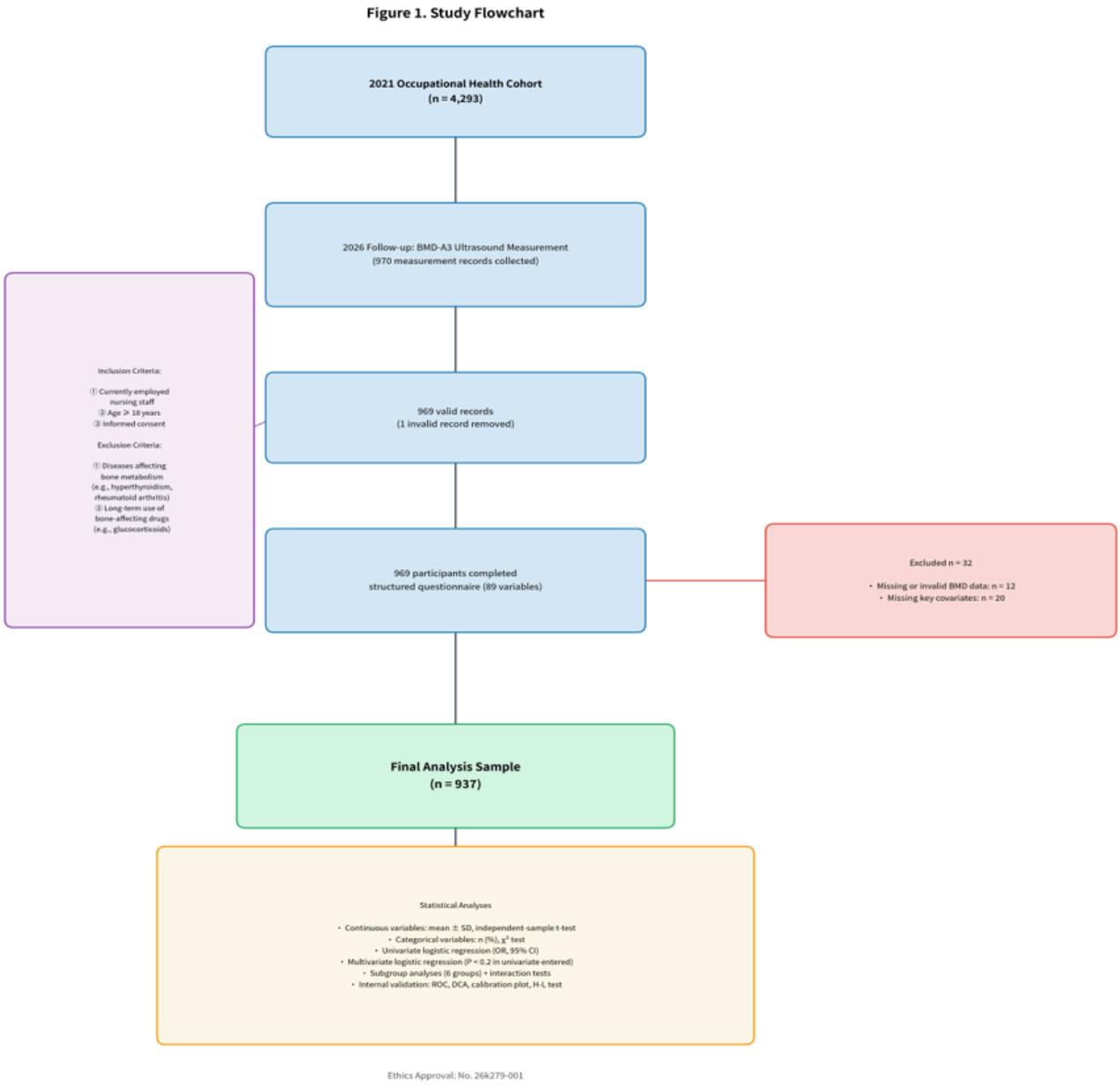


Figure 1

Flowchart of study participants. Nurses initially enrolled in the 2021 occupational health cohort (n = 4,293) were followed up in 2026; 969 participated in the BMD sub-study, and 937 with complete data were included in the analysis.

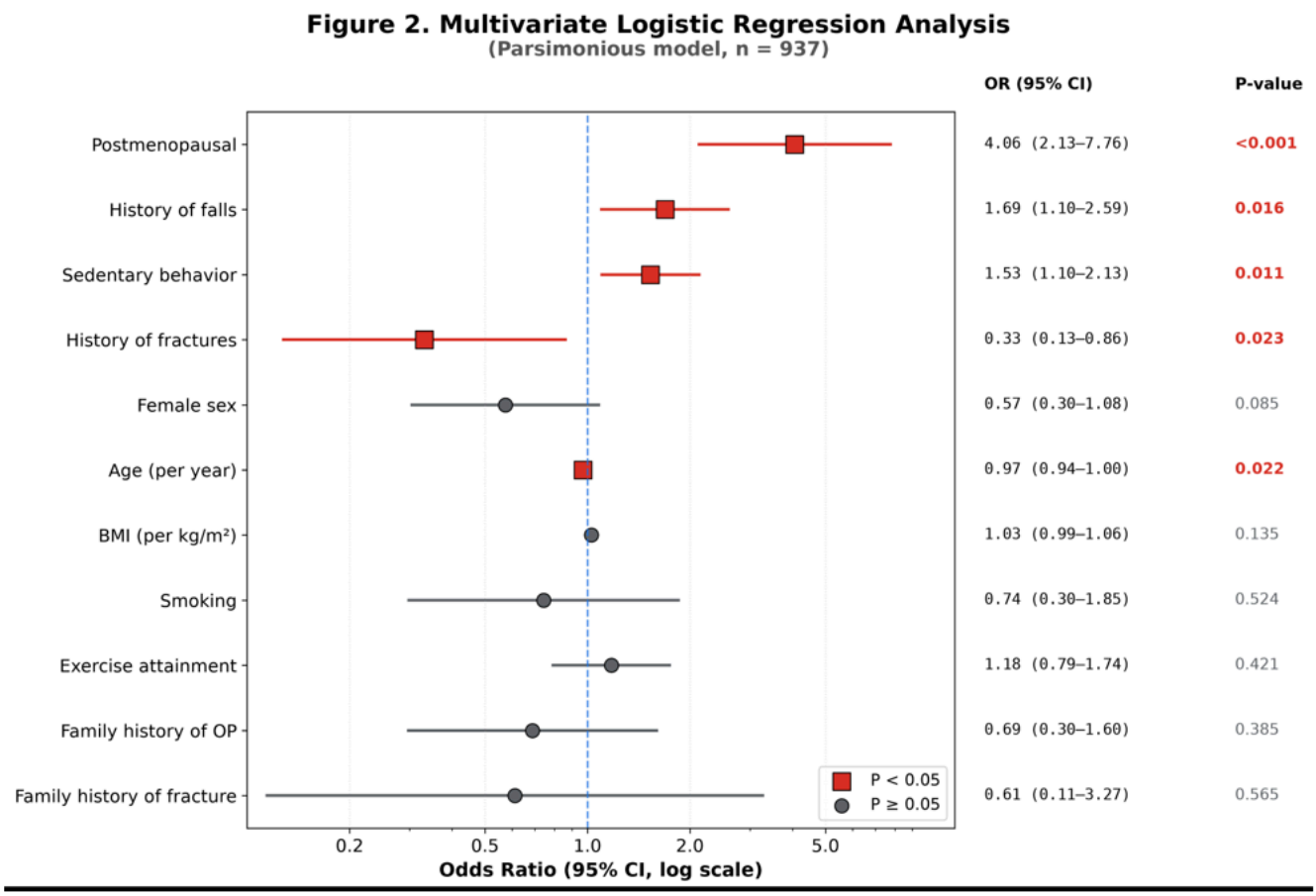


Figure 2

Multivariate logistic regression forest plot. Odds ratios and 95% confidence intervals for factors associated with low bone mass (n = 937). Red squares indicate statistically significant associations (P < 0.05).

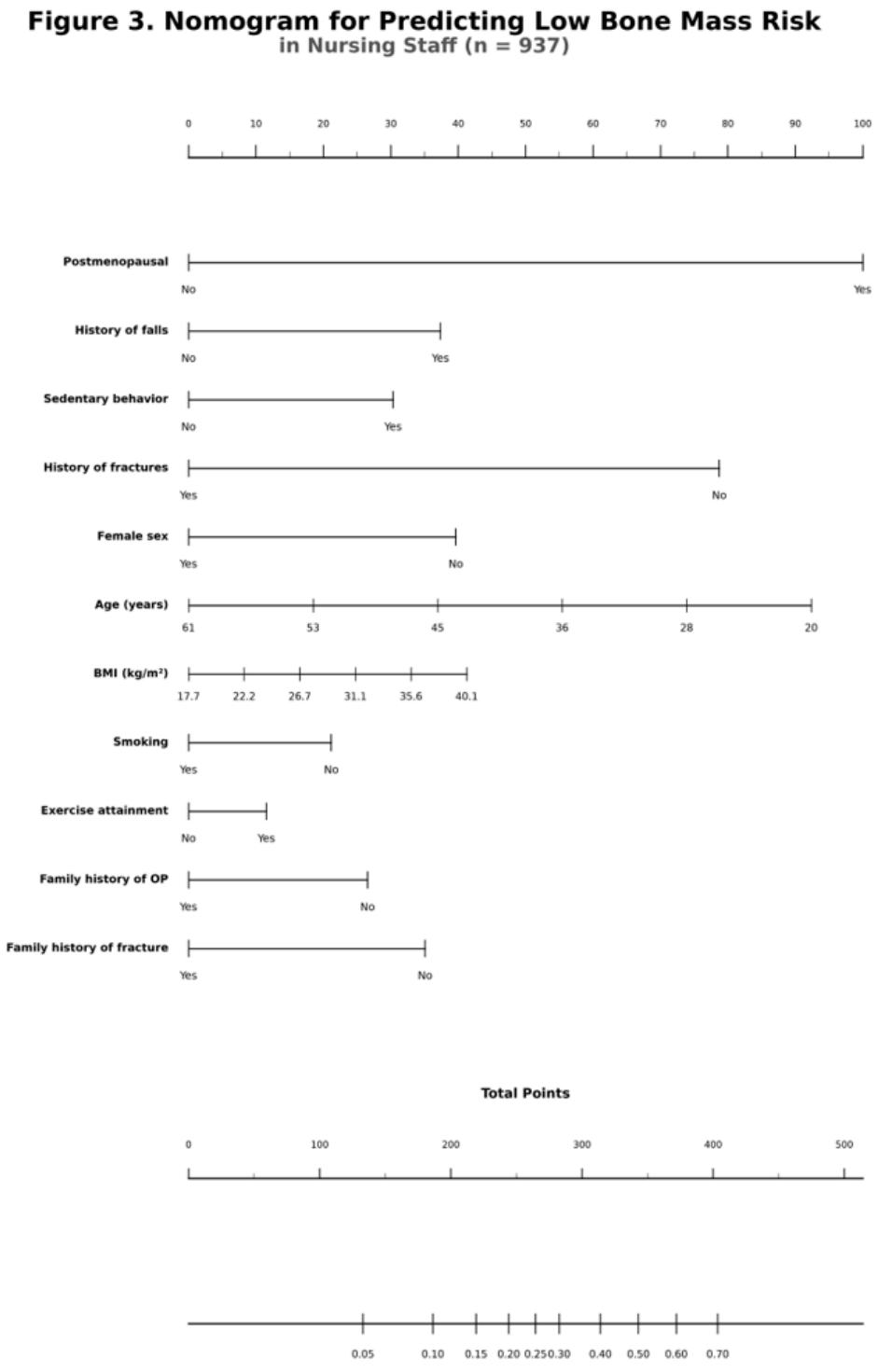


Figure 3

Nomogram for predicting low bone mass risk in nursing staff. Each predictor corresponds to a point value on the top axis; the total points are mapped to the predicted probability on the bottom axis.

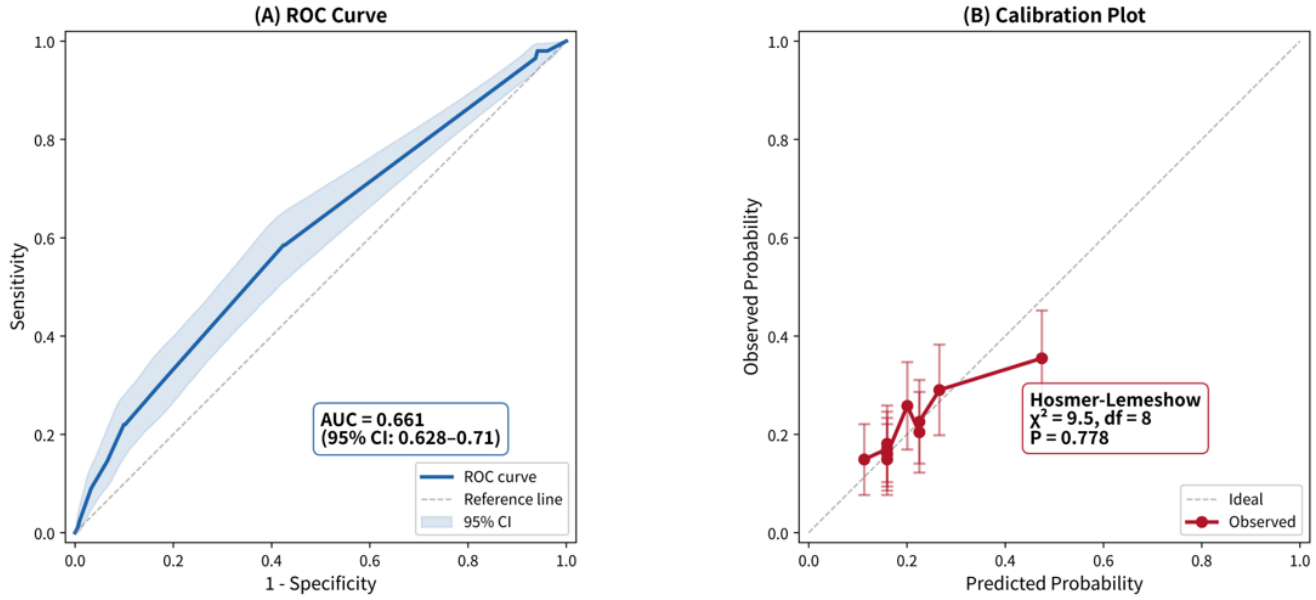


Figure 4

Model discrimination and calibration. (A) Receiver operating characteristic (ROC) curve for the multivariate model (AUC = 0.661, 95% CI 0.628–0.710). (B) Calibration plot of predicted versus observed probability of low bone mass, with bootstrap 95% confidence bands.

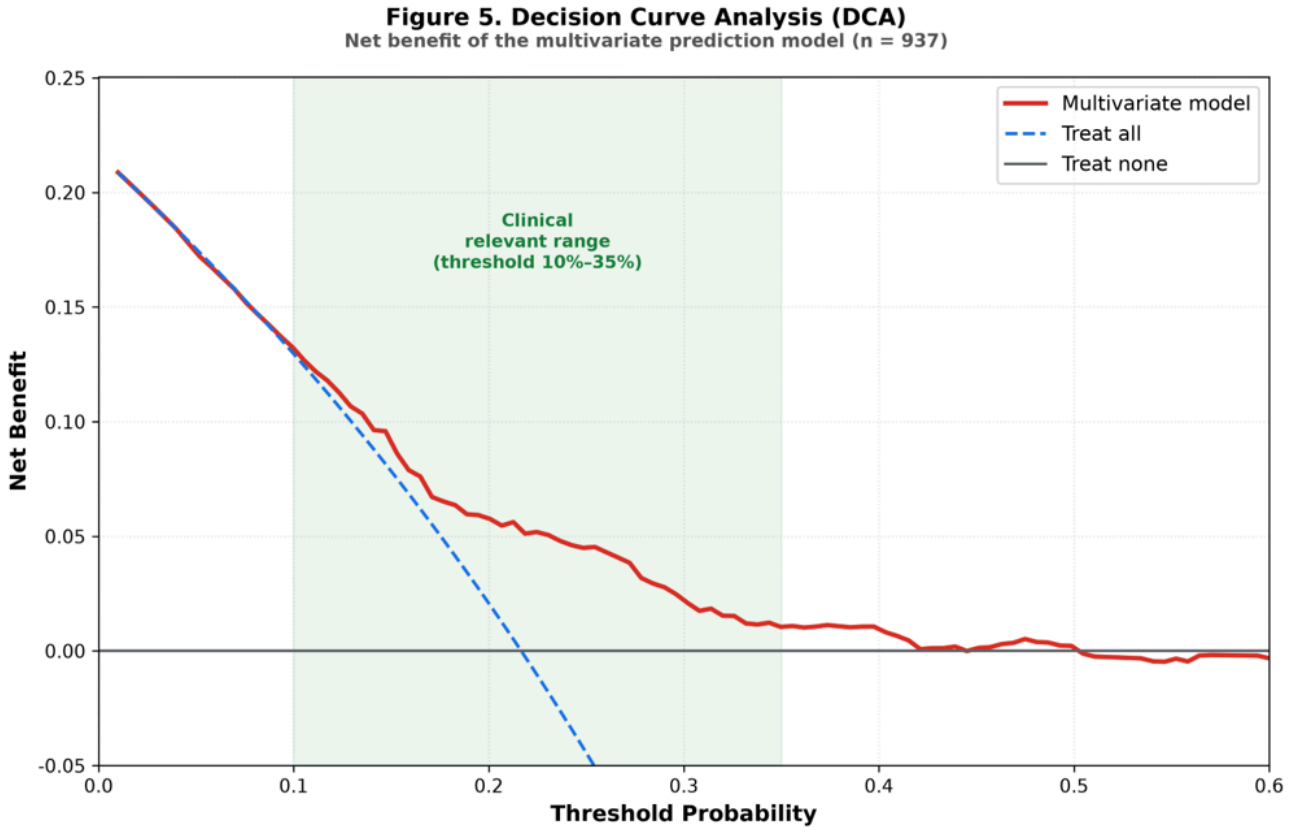


Figure 5

Decision curve analysis (DCA). Net clinical benefit of the nomogram (blue line) compared with treat-all (gray line) and treat-none (horizontal black line) strategies across threshold probabilities.

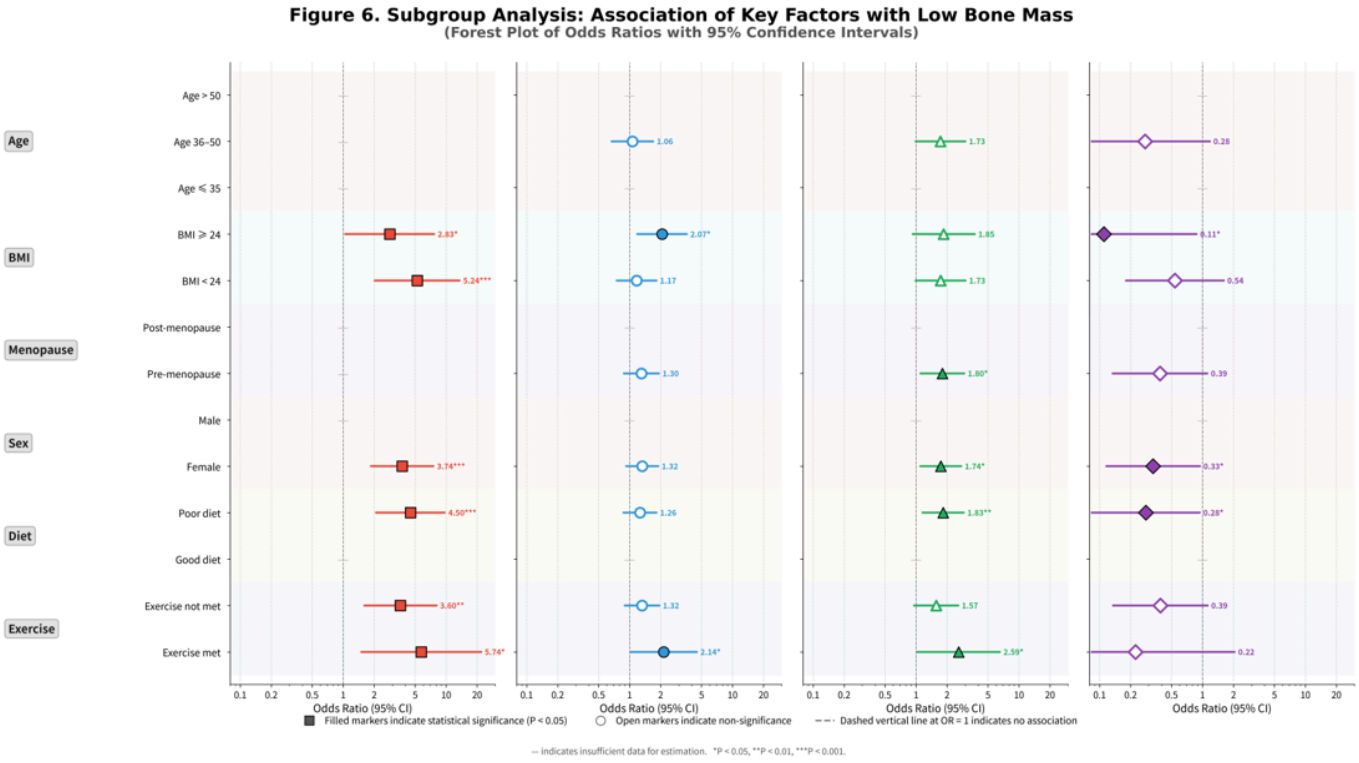


Figure 6

Subgroup analysis forest plot. Odds ratios and 95% confidence intervals for the association between sedentary behavior and low bone mass across six subgroup dimensions (13 strata).