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*Original Research*

# Analysis of Factors Influencing Bone Mineral Density in Postmenopausal Women: A Cross-Sectional Study and Implications for Nursing Practice

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**Abstract**

**Background:** To analyze the bone mineral density (BMD) status of postmenopausal women, thereby providing a basis for precise clinical nursing interventions, an area that remains underexplored in tailored gerontological nursing practice. **Methods:** This was a retrospective and cross-sectional study. A total of 1375 postmenopausal women aged 45–59 years who underwent BMD examination at Jinhua Hospital of Zhejiang University from January 1, 2025, to December 31, 2025 were retrospectively enrolled. Demographic data, bone metabolism markers, sex hormones, blood lipids, and other relevant indices were collected. Participants were categorized into three groups based on BMD results: normal BMD, osteopenia, and osteoporosis. Intergroup comparisons were performed using the Kruskal-Wallis test, one-way analysis of variance (ANOVA), or the $\chi^2$ test. Independent associated factors were identified using multinomial logistic regression, and subgroup analyses were performed. **Results:** Subgroup analysis revealed that BMD decreased with increasing age ($p < 0.001$) and decreasing body mass index (BMI) ($p < 0.001$), and that BMD distribution also differed among occupational types ($p = 0.001$). Compared with the normal BMD group, univariate analysis and multinomial logistic regression showed that older age, lower BMI, lower serum calcium, and elevated alkaline phosphatase (ALP) were independently associated with osteopenia ($p < 0.05$ for all). Estradiol levels also showed a statistically significant but clinically negligible association ($p = 0.035$). Older age, lower BMI, elevated ALP, lower testosterone, and elevated lipoprotein(a) levels were identified as independent predictors for osteoporosis ($p < 0.05$ for all). **Conclusions:** Increasing age, low BMI, increased bone turnover, reduced testosterone, and elevated lipoprotein(a) were identified as factors significantly associated with reduced BMD in postmenopausal women.

**Keywords:** bone mineral density; postmenopausal middle-aged women; influencing factors; nursing countermeasures

## 1. Introduction

Osteoporosis is a systemic skeletal disorder characterized by reduced bone mass and deterioration of bone microarchitecture. It is associated with an increased risk of fractures, disability, and mortality, thus representing a major global health challenge for middle-aged and older adults [1]. Following menopause, the decline in ovarian function and the consequent reduction in estrogen levels lead to a significantly accelerated rate of bone loss in women, placing this population at high risk for osteoporosis [2,3]. Up to 40% of women will experience an osteoporotic fracture after 50 years of age. with hip fractures in particular associated with severe disability and increased mortality [4,5].

Bone mineral density (BMD), measured by dual-energy X-ray absorptiometry (DXA), is the gold standard for osteoporosis diagnosis [6,7]. Previous studies have identified age, years since menopause, body mass index (BMI), physical activity, calcium and vitamin D intake, as well as bone turnover markers as key determinants of bone health in postmenopausal women [8,9,10]. However, the effects of these factors vary significantly across geographic regions and populations [11].

In recent years, the research perspective on osteoporosis has expanded beyond traditional endocrine metabolism to include broader cardiometabolic pathways and the sex hormone axis. Multiple studies suggest that dyslipidemia, elevated lipoprotein(a), and reduced endogenous androgen levels may be associated with reduced BMD in postmenopausal women; however, existing evidence remains inconsistent. Furthermore, there is a paucity of localized, region-specific data focusing on middle-aged women in defined populations [12,13,14], particularly integrating emerging biomarkers, to inform clinical practice [15]. Currently, nursing interventions for osteoporosis rely heavily on generalized health education, with limited evidence-based pathways tailored to quantifiable individual-level risk factors [15].

Therefore, this study conducted a retrospective analysis of 1375 postmenopausal women aged 45-59 years in the Jinhua region. We aimed to characterize the distribution of BMD status in this population, identify independent risk factors for osteopenia and osteoporosis, and provide an evidence-based foundation for the development of regionalized and individualized nursing intervention strategies.

## 2. Materials and Methods

### 2.1 Patient Selection

This was a retrospective, cross-sectional study involving consecutive sampling. A total of 1375 postmenopausal women aged from 45 to 59 years who underwent osteoporosis screening at Jinhua Hospital of Zhejiang University from January 1, 2025, to December 31, 2025. The inclusion criteria were as follows: (1) females aged 45–59 years; (2) natural menopause for ≥ 1 year; and (3) completion of BMD testing and measurement of relevant blood biochemical indicators. The exclusion criteria were as follows: (1) secondary osteoporosis; (2) long-term use of medications affecting bone metabolism; (3) severe liver or kidney dysfunction; and (4) a history of recent fractures or surgery in the lumbar spine or hip joint. For each patient, we collected general demographic data, including age, BMI, occupation, and number of pregnancies. Blood biochemical indicators measured within 3 months of the BMD examination were compiled, including bone metabolism markers (total 25-hydroxyvitamin D, N-terminal osteocalcin, parathyroid hormone, calcitonin, serum calcium, β-CrossLaps [β-CTx], and alkaline phosphatase [ALP]), sex hormones (testosterone, follicle-stimulating hormone, and estradiol), and lipid profiles (low-density lipoprotein cholesterol, total cholesterol, triglycerides, lipoprotein(a), apolipoprotein A, apolipoprotein B, and high-density lipoprotein cholesterol). This study was approved by the Ethics Committee of Jinhua Municipal Central Hospital.

### 2.2 BMD Measurement and Diagnostic Criteria

In this study, BMD was measured using DXA with a Prodigy Primo scanner (Model Prodigy Primo, GE Healthcare, 350222MA, Madison, WI, USA), which is currently recognized as the gold standard for BMD assessment.

Calibration protocol and quality control: Daily calibration was performed each morning prior to patient scanning using a manufacturer-provided spine phantom, in accordance with the instrument's standard operating procedures. The coefficient of variation for BMD measurements was maintained at < 1.0% throughout the study period, ensuring instrument stability and measurement accuracy. All scans were conducted by certified nuclear medicine technicians who had received standardized training, and all images and reports were reviewed and approved by licensed nuclear medicine physicians.

Diagnostic criteria: Regions of interest (ROIs) were delineated at the anteroposterior lumbar spine (L1-L4), femoral neck, total hip, and the 33% radius site. The lowest T-score among these sites was then selected for diagnosis. Based on the World Health Organization (WHO) classification criteria for postmenopausal women, participants were categorized into three groups: normal bone mass (T-score ≥ –1.0), osteopenia (–2.5 < T-score < –1.0), and osteoporosis (T-score ≤ –2.5) [16]. Participants with severe osteoporosis (T-score ≤ –2.5 with fragility fracture) were included in the osteoporosis group for analysis.

### 2.3 Blood Biochemical Indicator Testing

Venous blood samples were collected from all subjects after an overnight fast of the following key indicators were measured: (1) bone metabolism markers (25-hydroxyvitamin D, N-terminal osteocalcin, parathyroid hormone, calcitonin, serum calcium, ALP, and β-CTx); (2) sex hormones (estradiol, follicle-stimulating hormone, and testosterone); and (3) lipid profile (low-density lipoprotein, total cholesterol, triglycerides, lipoprotein(a), apolipoprotein A, apolipoprotein B, and high-density lipoprotein).

### 2.4 Statistical Analysis

Data analysis was performed using the Statistical Package for the Social Sciences (SPSS) (Version 20.0, IBM Corp., Armonk, NY, USA) and Python statistical software (Version 3.12.3, Python Software Foundation, Wilmington, DE, USA). Normality was assumed if the Shapiro-Wilk test $p$-value was > 0.05. Normally distributed continuous variables are expressed as the mean ± standard deviation ($\bar{x}$ ± SD), non-normally distributed variables as median (interquartile range, IQR), and categorical variables as number (percentage). Comparisons among the three BMD groups (normal, osteopenia, osteoporosis) were performed using the Kruskal-Wallis test for non-normally distributed continuous variables or one-way analysis of variance (ANOVA) for normally distributed variables. Intergroup comparisons for categorical variables were performed using the chi-squared test. Benjamini-Hochberg false discovery rate (FDR) correction was applied to all $p$-values obtained from the univariate analyses (Kruskal-Wallis test, ANOVA, and chi-square test). Multinomial logistic regression models were used for multivariate analysis, utilizing the normal BMD group used as the reference category. Two logit models were established to calculate odds ratios (ORs) and 95% confidence intervals (CIs). Stratified analysis was performed based on age, BMI, and occupation type. Model fit was assessed using the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). Lower AIC and BIC values indicate a better model fit. The likelihood ratio test was also used to compare the final model with the intercept-only model. $p < 0.05$ was considered statistically significant.

## 3. Results

Baseline characteristics of the 1375 postmenopausal women aged 45–59 years included in the study are shown in Table 1. The median age was 55.00 years (IQR: 52.00–57.00), and the median BMI was 23.05 kg/m$^2$ (IQR: 21.03–25.03). Among the participants, 54.1% had given birth to 0–1 child, 40.8% had two children, and 5.2% had three or more children. Furthermore, 71.9% were engaged in physical labor, whereas 28.1% were engaged in mental labor. Re-

**Table 1. Baseline demographics, bone metabolism, hormone, and lipid profiles in postmenopausal women aged 45–59 years (n = 1375).**

| Parameter | Cases (n) | Median (IQR) |
|---|---|---|
| Age (years) | 1375 | 55.00 (52.00, 57.00) |
| Parity (n) | 1345 | |
| 0–1 | 727 | |
| 2 | 548 | |
| ≥3 | 70 | |
| Occupation Type | 761 | |
| Mental labor | 214 | |
| Manual work | 547 | |
| BMI (kg/m$^2$) | 1375 | 23.05 (21.03, 25.03) |
| Total 25-Hydroxyvitamin D (ng/mL) | 364 | 19.88 (15.62, 23.48) |
| N-terminal Osteocalcin (ng/mL) | 211 | 19.66 (13.47, 29.40) |
| Parathyroid Hormone (pg/mL) | 201 | 41.70 (25.80, 57.80) |
| Calcitonin (pg/mL) | 153 | 1.72 (1.38, 2.33) |
| Serum Calcium (mmol/L) | 1249 | 2.29 (2.21, 2.36) |
| β-CTx (ng/mL) | 211 | 0.71 (0.51, 1.02) |
| ALP (U/L) | 1344 | 77.00 (62.00, 93.00) |
| Testosterone (ng/mL) | 188 | 0.94 (0.64, 1.43) |
| Follicle-Stimulating Hormone (mIU/mL) | 199 | 41.51 (26.84, 59.50) |
| Estradiol (pg/mL) | 161 | 55.10 (55.10, 93.48) |
| Low-Density Lipoprotein Cholesterol (mmol/L) | 1323 | 3.04 (2.61, 3.50) |
| Total Cholesterol (mmol/L) | 1323 | 4.80 (4.12, 5.48) |
| Triglycerides (mmol/L) | 1323 | 1.35 (0.95, 1.92) |
| Lipoprotein(a) (mg/L) | 1044 | 126.00 (56.00, 285.00) |
| Apolipoprotein A (g/L) | 1245 | 1.34 (1.19, 1.50) |
| Apolipoprotein B (g/L) | 1245 | 0.82 (0.69, 0.97) |
| High-Density Lipoprotein Cholesterol (mmol/L) | 1323 | 1.29 (1.11, 1.50) |

Data are presented as median (IQR) for continuous variables, and as number (n) for categorical variables. BMI, body mass index; ALP, alkaline phosphatase; β-CTx, β- Cross-Laps; IQR, interquartile range.

garding bone metabolism, vitamin D levels were generally low in this population, with a median 25-hydroxyvitamin D level of 19.88 ng/mL. Some bone turnover markers (N-terminal osteocalcin, β-CTx) showed considerable interindividual variability. Sex hormone levels (testosterone, follicle-stimulating hormone, and estradiol) were consistent with a postmenopausal status. Lipid parameters suggested that some participants may exhibit suboptimal lipid profiles.

Fig. 1 illustrates the distribution of BMD among postmenopausal women, stratified by age, BMI, and occupation type. For the stratified analysis, participants were categorized by age groups (45–49, 50–54, and 55–59 years), BMI categories based on the WHO Asia-Pacific classification (underweight: <18.5 kg/m$^2$; normal: 18.50–23.9 kg/m$^2$; overweight: 24.0–27.9 kg/m$^2$; obese: ≥28.0 kg/m$^2$) [17], and occupation type (mental labor vs. manual work). With increasing age, the proportion of participants with normal BMD decreased, whereas the proportions of those with osteopenia and osteoporosis showed an upward trend. A positive correlation was observed between BMI and healthy bone status (Pearson's r = 0.603, $p < 0.0001$), with a clear dose-response pattern. Regarding occupation type, the proportion of individuals engaged in manual work with normal BMD was lower than that of those engaged in mental labor, whereas the proportion with osteoporosis was higher among manual laborers ($p = 0.001$). These findings suggest that differences in bone health status may exist across different patterns of occupational activity.

Univariate analysis revealed significant differences among the three BMD groups for age, occupation, parity, BMI, N-terminal osteocalcin, ALP, testosterone, estradiol, low-density lipoprotein, triglycerides, and apolipoprotein B ($p < 0.05$ for all; all remained significant after FDR correction). Serum calcium showed a nominal association in the uncorrected analysis ($p = 0.046$) but did not remain statistically significant after FDR correction (adjusted $p = 0.064$). Lipoprotein(a) showed a trend toward significance in the uncorrected analysis ($p = 0.053$) but was not significant after FDR correction (adjusted $p = 0.069$). No significant differences were observed for total 25-hydroxyvitamin D, parathyroid hormone, calcitonin, β-

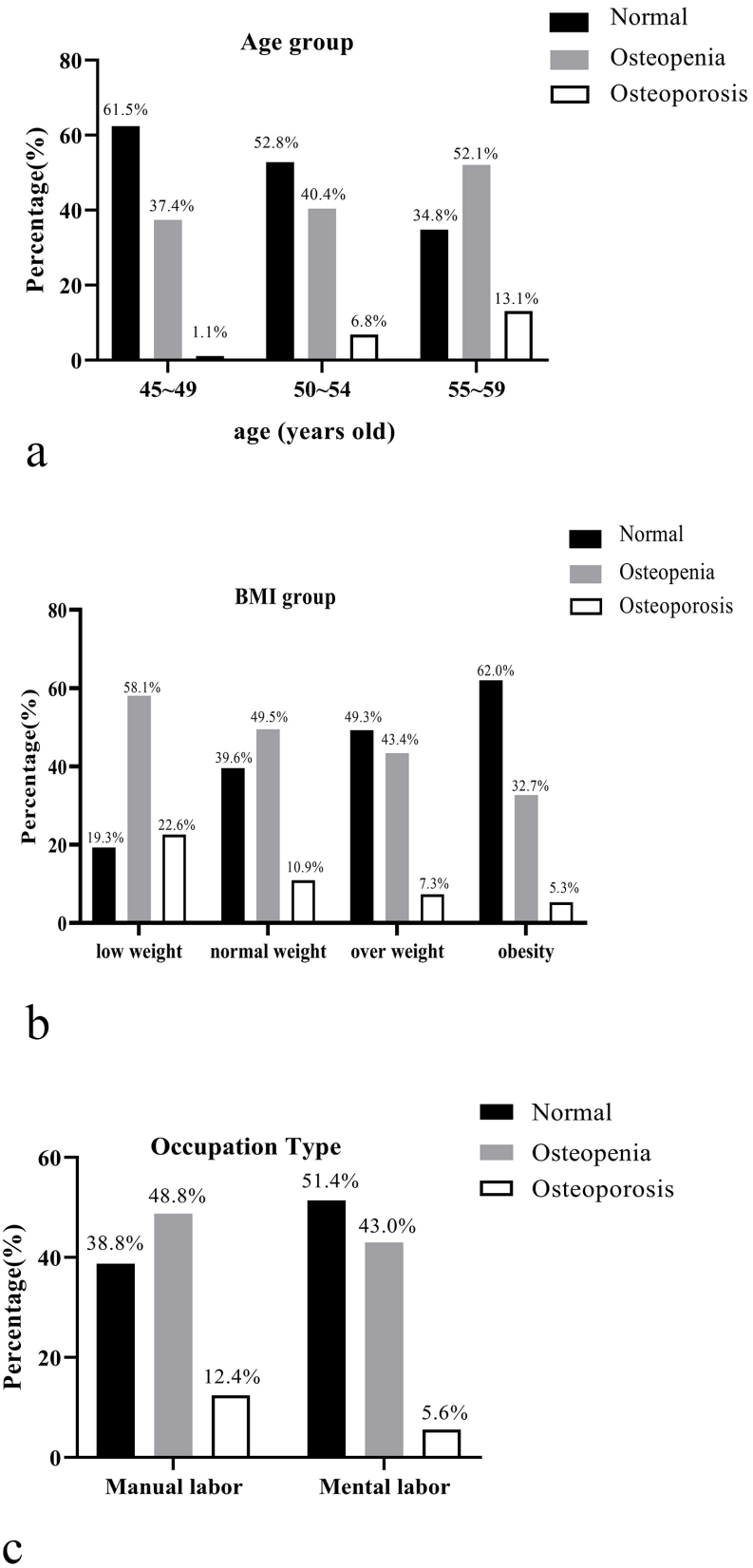


**Fig. 1. BMD distribution of postmenopausal women**. (a) Age stratification; (b) BMI stratification; (c) Occupational type stratification. BMD, bone mineral density.

**Table 2. Univariate analysis of factors associated with BMD in postmenopausal women aged 45–59 years.**

| Parameter | Statistical value | *p*-value | FDR-adjusted *p*-value | Normal group | Osteopenia group | Osteoporosis group |
|---|---|---|---|---|---|---|
| Age (years) | 92 | <0.001 | <0.001 | 54.00 (52.00, 56.00) | 56.00 (53.00, 58.00) | 57.00 (54.00, 59.00) |
| Occupation Type | 13.73 | 0.001 | 0.003 | | | |
| Manual work | | | | 212 | 267 | 68 |
| Mental labor | | | | 110 | 92 | 12 |
| Parity | 15.24 | 0.004 | 0.008 | | | |
| 0–1 | | | | 316 | 353 | 58 |
| 2 | | | | 244 | 237 | 67 |
| ≥3 | | | | 19 | 42 | 9 |
| BMI (kg/m$^2$) | 56.90 | <0.001 | <0.001 | 23.44 (21.87, 25.78) | 22.66 (21.01, 24.65) | 21.97 (20.00, 24.03) |
| Total 25-Hydroxyvitamin D (ng/mL) | 0.27 | 0.765 | 0.765 | 19.86 ± 6.32 | 19.98 ± 6.95 | 20.72 ± 6.27 |
| N-terminal Osteocalcin (ng/mL) | 10.92 | 0.004 | 0.008 | 17.14 (13.45, 23.54) | 20.71 (15.00, 31.06) | 21.74 (16.06, 35.97) |
| Parathyroid Hormone (pg/mL) | 5.35 | 0.069 | 0.085 | 42.40 (29.75, 55.40) | 39.65 (29.35, 53.28) | 46.65 (36.80, 67.05) |
| Calcitonin (pg/mL) | 2.33 | 0.312 | 0.312 | 1.73 (1.40, 2.21) | 1.70 (1.42, 2.20) | 2.07 (1.41, 3.06) |
| Serum Calcium (mmol/L) | 6.17 | 0.046 | 0.064 | 2.30 (2.23,2.36) | 2.28 (2.22, 2.35) | 2.28 (2.20, 2.36) |
| β-CTx (ng/mL) | 4.99 | 0.083 | 0.094 | 0.66 (0.48, 1.00) | 0.86 (0.57, 1.16) | 0.65 (0.47, 1.18) |
| ALP (U/L) | 14.23 | 0.0008 | 0.003 | 74.00 (62.00, 89.00) | 79.00 (67.00, 92.00) | 80.50 (64.75, 99.25) |
| Testosterone (ng/mL) | 9.46 | 0.009 | 0.014 | 1.01 (0.68, 1.56) | 0.92 (0.65, 1.41) | 0.64 (0.51, 0.87) |
| Follicle-Stimulating Hormone (mIU/mL) | 2.37 | 0.096 | 0.104 | 41.91 ± 23.93 | 49.76 ± 26.58 | 42.66 ± 13.60 |
| Estradiol (pg/mL) | 7.67 | 0.022 | 0.032 | 55.10 (55.10, 103.90) | 55.10 (55.10, 56.85) | 55.10 (55.1, 55.1) |
| Low-Density Lipoprotein Cholesterol (mmol/L) | 9.38 | 0.009 | 0.014 | 3.05 (2.61, 3.60) | 3.05 (2.57, 3.54) | 2.85 (2.33, 3.43) |
| Total Cholesterol (mmol/L) | 5.14 | 0.076 | 0.090 | 4.83 (4.21, 5.55) | 4.79 (4.18, 5.52) | 4.62 (3.91, 5.39) |
| Triglycerides (mmol/L) | 10.71 | 0.005 | 0.009 | 1.38 (0.99, 1.93) | 1.35 (0.99, 1.90) | 1.12 (0.90, 1.62) |
| Lipoprotein(a) (mg/L) | 5.88 | 0.053 | 0.069 | 118.00 (61.00, 256.00) | 130.50 (61.00, 282.25) | 162.00 (83.00, 352.00) |
| Apolipoprotein A (g/L) | 1.20 | 0.550 | 0.550 | 1.33 (1.21, 1.48) | 1.34 (1.21, 1.49) | 1.37 (1.22, 1.53) |
| Apolipoprotein B (g/L) | 12.29 | 0.002 | 0.005 | 0.84 (0.70, 1.00) | 0.81 (0.67, 1.00) | 0.75 (0.62, 0.93) |
| High-Density Lipoprotein Cholesterol (mmol/L) | 4.12 | 0.128 | 0.133 | 1.27 (1.08, 1.52) | 1.30 (1.11, 1.52) | 1.32 (1.13, 1.60) |

Data are presented as median (IQR) for continuous variables and as number (n) for categorical variables. Comparisons among three groups were performed using the Kruskal-Wallis test (for continuous variables) or the Chi-squared test (for categorical variables). p-values were adjusted using the Benjamini-Hochberg FDR method to account for multiple comparisons. Bold indicates statistical significance after FDR correction (adjusted p < 0.05).* BMD, bone mineral density; FDR, false discovery rate.

CTx, follicle-stimulating hormone, total cholesterol, high-density lipoprotein cholesterol, or apolipoprotein A ($p$ > 0.05 for all) (Table 2).

Variables identified as significant ($p$ < 0.05) in the univariate analysis were subsequently included in the multinomial logistic regression model (Table 3). Compared with individuals with normal BMD, osteopenia was independently associated with older age, lower BMI, lower serum calcium, higher ALP, and higher estradiol. Compared with normal BMD, osteoporosis was significantly associated with age, BMI, ALP, testosterone, and lipoprotein(a). ALP ($p$ = 0.015) and lipoprotein(a) ($p$ = 0.041) were positively correlated with osteoporosis, while serum testosterone exhibited a negative correlation (OR = 0.10; 95% CI: 0.02–0.50, $p$ = 0.005).

## 4. Discussion

This study retrospectively analyzed BMD status and its associated multifactorial correlates among 1375 postmenopausal women aged 45–59 years in the Jinhua region. The primary aim was to extend beyond established demographic and lifestyle factors by incorporating an expanded panel of biochemical indicators, encompassing markers of bone metabolism, sex hormones, and lipid profiles, to identify independent risk factors for osteopenia and osteoporosis. This study addresses a key gap in the literature, namely

**Table 3. Multinomial logistic regression analysis of factors associated with osteopenia and osteoporosis in postmenopausal women aged 45–59 years.**

| | Parameter | Regression Coefficient (B) | SE | Wald Statistic | *p*-Value | OR | 95% CI |
|---|---|---|---|---|---|---|---|
| Osteopenia Group vs. Normal BMD Group | Age (years) | 0.145 | 0.020 | 50.834 | <0.0001 | 1.16 | [1.11, 1.20] |
| | BMI (kg/m$^2$) | –0.125 | 0.020 | 37.700 | <0.0001 | 0.88 | [0.85, 0.92] |
| | Serum Calcium | –1.453 | 0.590 | 6.076 | 0.014 | 0.23 | [0.07, 0.74] |
| | ALP | 0.009 | 0.003 | 11.253 | 0.001 | 1.01 | [1.00, 1.01] |
| | Estradiol | 0.002 | 0.001 | 4.445 | 0.035 | 1.00 | [1.00, 1.01] |
| Osteoporosis Group vs. Normal BMD Group | Age (years) | 0.274 | 0.039 | 49.335 | <0.0001 | 1.32 | [1.22, 1.42] |
| | BMI (kg/m$^2$) | –0.224 | 0.036 | 38.977 | <0.0001 | 0.80 | [0.75, 0.86] |
| | ALP | 0.010 | 0.004 | 5.893 | 0.015 | 1.01 | [1.00, 1.02] |
| | Testosterone | –2.307 | 0.825 | 7.822 | 0.005 | 0.10 | [0.02, 0.50] |
| | Lipoprotein(a) | 0.001 | 0.001 | 4.167 | 0.041 | 1.00 | [1.00, 1.01] |

Likelihood ratio test: $\chi^2 = 46.48$, df = 10, $p < 0.001$. AIC decreased from 624.00 (intercept-only) to 293.78 (final model); BIC decreased from 1575.56 to 299.87, indicating improved model fit.

The normal BMD group was used as the reference category. Variables included in the model were those with $p < 0.05$ in the univariate analysis. B, regression coefficient; SE, standard error; OR, odds ratio; CI, confidence interval.

the lack of comprehensive, region-specific data that can be translated into precise, evidence-based nursing interventions for this high-risk population. While current guidelines acknowledge multifactorial influences, there remains a lack of actionable frameworks that stratify risk using quantifiable clinical and biochemical parameters to guide tailored nursing care [15]. Our findings therefore provide a localized evidence base to support the development of such stratified management strategies.

Our analysis indicated that the incidence of osteopenia and osteoporosis among postmenopausal women was closely associated with specific factors, including age, BMI, dyslipidemia, and testosterone levels. Bone health management should therefore comprehensively consider the interplay between endocrine and cardiovascular metabolic indicators. In guidelines published by the Endocrine Society, Eastell et al. [18] reported that osteoporosis management in postmenopausal women should account for multiple metabolic factors. This recommendation is strongly supported by our present findings.

Our findings further indicated that increasing age and hormonal changes are independent risk factors for reduced BMD in postmenopausal women, consistent with the results reported by Salari et al. [19]. BMI exhibited a strong correlation with osteoporosis, and moderate body weight exerted a protective effect on bone, consistent with the findings of Clynes et al. [20,21]. Several previous studies suggest that lipid metabolism imbalance may induce significant oxidative stress, inhibit osteoblast differentiation, and promote osteoclast activity, thereby affecting bone metabolism [22]. An earlier meta-analysis found a significant inverse correlation between serum lipid levels and BMD in postmenopausal women [23]. In the present study, we identified an association between testosterone levels and osteoporosis, consistent with the findings reported by Yang et al. [24] regarding the role of androgens in maintaining bone health in women. Zhao et al. [25] reported a strong association between osteoporosis and lipid profiles in postmenopausal women. Given the relatively younger age of subjects in the present study, the influence of lipid metabolism on bone health may already be evident in the early postmenopausal stage. However, the association between lipoprotein(a) and BMD did not remain statistically significant after FDR correction for multiple comparisons (adjusted $p = 0.069$), thus suggesting that this finding should be interpreted with caution and warrants further validation in larger cohorts.

In summary, bone health management in postmenopausal women should emphasize targeted nursing strategies. First, in line with the protective effect of moderate BMI, nurses should provide individualized nutritional counseling to support adequate caloric and protein intake and maintain a healthy weight [26]. Second, given the strong association with advancing age, routine BMD screening should be prioritized for women aged ≥ 45 years, consistent with current recommendations [27]. Third, health education should be strengthened to raise public awareness of osteoporosis risks. In patients with elevated ALP, regular monitoring and evaluation for secondary causes of high bone turnover should be integrated into nursing follow-up protocols [26]. In addition, lifestyle modifications should be encouraged, such as regular physical activity, balanced nutrition, smoking cessation, and alcohol moderation, to maintain a healthy body weight and metabolic balance, as supported by systematic reviews [7,15,27]. For individuals with dyslipidemia, collaborative management involving endocrinology and cardiology services is recommended. Nurses should adopt a holistic approach, educating patients on shared risk factors for cardiovascular disease and bone health, including smoking cessation and physical activity [28,29]. Finally, regular monitoring and follow-up of BMD should be implemented to enable dynamic, comprehensive management of bone health.

This study aimed to conduct a comprehensive multifactorial assessment in postmenopausal women, a population that experiences a critical window of bone loss, to facilitate early risk identification. In addition, the analysis incorporated cardiovascular and hormonal metabolic indicators, such as lipid profiles and testosterone levels, thereby expanding the conventional framework on osteoporosis risk factors [30].

The present study, conducted in the Jinhua region of Zhejiang Province, identified a distinct risk profile for bone loss in this specific population. Compared with data from large metropolitan centers or northern Chinese cities, our cohort exhibited relatively lower serum 25-hydroxyvitamin D levels (median: 19.88 ng/mL), suggesting a high prevalence of subclinical vitamin D insufficiency despite the region's sunny climate. This paradox may be attributed to cultural practices, dietary habits such as low calcium intake, or urban lifestyles that limit sun exposure. Furthermore, the significant association between occupational type (manual *vs.* mental labor) and BMD distribution ($p = 0.001$) highlights the impact of socioeconomic and behavioral factors specific to this region.

These regional characteristics directly inform the development of regionalized and individualized nursing intervention strategies proposed in our study objectives. First, given the low vitamin D status coupled with the observed protective effect of moderate BMI, nurses in this region should prioritize nutritional education that emphasizes both adequate caloric intake and vitamin D and calcium supplementation, tailored to local food availability. Second, risk stratification by occupational type suggests that workplace health promotion programs may be beneficial. Indeed, for manual laborers, nursing interventions should focus on injury prevention and joint protection, whereas for sedentary workers, emphasis should be placed on promoting weight-bearing physical activity to counteract inactivity. Finally, the observed association between elevated lipoprotein(a) and osteoporosis highlights the need for an integrated nursing approach that addresses both cardiovascular and bone health, particularly in the context of dietary transitions occurring in rapidly developing regions such as Jinhua. By integrating these region-specific findings into clinical pathways, nursing practice can extend beyond general guidelines to deliver more precise and context-appropriate care.

*Limitations*

This study has several limitations. First, as a single-center retrospective study, our sample may not be fully representative of the broader population of postmenopausal women across different geographic regions or healthcare settings. Despite the large sample size (n = 1375) providing statistical power and our detailed inclusion and exclusion criteria supporting internal validity, our findings may still reflect regional characteristics specific to Jinhua. Therefore, caution is warranted when extrapolating these results to other populations. Second, certain variables, such as dietary habits, and physical activity, and genetic factors, were not included in the analysis. Third, this study focused on a specific age group in a single geographic region (Jinhua); therefore, caution is warranted when extrapolating these findings to other populations or age groups. Fourth, due to the retrospective design, potentially important lifestyle and dietary factors could not be included in our analysis, such as physical activity levels, smoking status, alcohol consumption, and dietary calcium or vitamin D intake. These variables are known to influence bone metabolism, and their absence may introduce residual confounding. Finally, due to the retrospective design, several potentially important confounders could not be fully captured or adjusted for, including time since menopause, hormone replacement therapy use, smoking status, physical activity levels, and specific comorbidities, such as thyroid disease and diabetes. These variables are known to influence bone metabolism, and their absence from our multivariate model may have introduced residual confounding. Future multicenter studies should systematically collect these variables, increase sample size, extend follow-up duration, and develop more comprehensive risk prediction models for osteoporosis, thereby providing stronger evidence to support regionalized and personalized nursing approaches.

## 5. Conclusions

Our findings suggest that older age, lower BMI, elevated ALP, reduced testosterone, and elevated lipoprotein(a) are independently associated with reduced BMD in postmenopausal women aged 45-59 years.

Future prospective studies with comprehensive data collection, including lifestyle factors, dietary intake, and physical activity, are warranted to validate these findings and to develop more robust risk prediction models for postmenopausal osteoporosis.

## Availability of Data and Materials

All data analysed during this study are included in this article. Further enquiries can be directed to the corresponding author.

## Author Contributions

KD conceived and designed this research study. XY, SW and HX acquired data. SW and YH analyzed and interpreted the data. XY drafted the manuscript and KD revised the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

## Ethics Approval and Consent to Participate

The study was carried out in accordance with the guidelines of the Declaration of Helsinki. The study was approved by the Ethics Committee of Jinhua Municipal Central Hospital (ethics approval number: 2026-43). Written informed consent for participation and the use of anonymized clinical data was obtained from all participants.


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## Conflicts of Interest

The authors declare no conflicts of interest.

## References


[1] Liu H, Ru H, Yu P, Wei W, Wang S. Atopic dermatitis and the risk of osteoporosis and fractures: a meta-analysis of cohort studies. Annals of Medicine. 2026; 58: 2607193. https://doi.org/10.1080/07853890.2025.2607193

[2] Kurtoglu-Aksoy N, Akhan SE, Bastu E, Gungor-Ugurlucan F, Telci A, Iyibozkurt AC, et al. Implications of premature ovarian failure on bone turnover markers and bone mineral density. Clinical and Experimental Obstetrics & Gynecology. 2014; 41: 149–153.

[3] Nosal BM, Aksenov A, Andersen C, Lee ECH, Zhou Y, Chun OK. The gut-bone axis: potential influence of anthocyanins and implications for postmenopausal osteoporosis. Food Science and Biotechnology. 2026; 35: 13–25. https://doi.org/10.1007/s10068-025-01907-x

[4] Greenstein AS, Gorczyca JT. Orthopedic Surgery and the Geriatric Patient. Clinics in Geriatric Medicine. 2019; 35: 65–92. https://doi.org/10.1016/j.cger.2018.08.007

[5] Sözen T, Özışık L, Başaran NÇ. An overview and management of osteoporosis. European Journal of Rheumatology. 2017; 4: 46–56. https://doi.org/10.5152/eurjrheum.2016.048

[6] GBD 2021 Low Bone Mineral Density Collaborators. The global, regional, and national burden attributable to low bone mineral density, 1990-2020: an analysis of a modifiable risk factor from the Global Burden of Disease Study 2021. The Lancet. Rheumatology. 2025; 7: e873–e894. https://doi.org/10.1016/S2665-9913(25)00105-5

[7] Kanis JA, Cooper C, Rizzoli R, Reginster JY, Scientific Advisory Board of the European Society for Clinical and Economic Aspects of Osteoporosis (ESCEO) and the Committees of Scientific Advisors and National Societies of the International Osteoporosis Foundation (IOF). European guidance for the diagnosis and management of osteoporosis in postmenopausal women. Osteoporosis International : a Journal Established as Result of Cooperation between the European Foundation for Osteoporosis and the National Osteoporosis Foundation of the USA. 2019; 30: 3–44. https://doi.org/10.1007/s00198-018-4704-5

[8] Peillex C, Pelletier M. The impact and toxicity of glyphosate and glyphosate-based herbicides on health and immunity. Journal of Immunotoxicology. 2020; 17: 163–174. https://doi.org/10.1080/1547691X.2020.1804492

[9] Zhang M, Li Y, Ma Q, Mao W, Gao Y, Liu Y, et al. Relevance of parathyroid hormone (PTH), vitamin 25(OH)D3, calcitonin (CT), bone metabolic markers, and bone mass density (BMD) in 860 female cases. Clinical and Experimental Obstetrics & Gynecology. 2015; 42: 129–132.

[10] Pouresmaeili F, Kamalidehghan B, Kamarehei M, Goh YM. A comprehensive overview on osteoporosis and its risk factors. Therapeutics and Clinical Risk Management. 2018; 14: 2029–2049. https://doi.org/10.2147/TCRM.S138000

[11] Panahi N, Saeedi Moghaddam S, Fahimfar N, Rezaei N, Sanjari M, Rashidi MM, et al. Trend in global burden attributable to low bone mineral density in different WHO regions: 2000 and beyond, results from the Global Burden of Disease (GBD) study 2019. Endocrine Connections. 2023; 12: e230160. https://doi.org/10.1530/EC-23-0160

[12] Hou YC, Wu CC, Liao MT, Shyu JF, Hung CF, Yen TH, et al. Role of nutritional vitamin D in osteoporosis treatment. Clinica Chimica Acta; International Journal of Clinical Chemistry. 2018; 484: 179–191. https://doi.org/10.1016/j.cca.2018.05.035

[13] Liu H, Yue X, Cui X, Wei W, Wang S. Association of the Alternative Healthy Eating Index with osteoporosis and muscle mass among U.S. adults aged 50 years and older. Nutricion Hospitalaria. 2026; 42: 1258–1268. https://doi.org/10.20960/nh.05989

[14] Haring B, Crandall CJ, Carbone L, Liu S, Li W, Johnson KC, et al. Lipoprotein(a) plasma levels, bone mineral density and risk of hip fracture: a post hoc analysis of the Women's Health Initiative, USA. BMJ open. 2019; 9: e027257. https://doi.org/10.1136/bmjopen-2018-027257.

[15] Liu Y, Zhang C, Zhang L, Ma X, Dong Z. Promoting and impeding factors for exercise in patients with osteopenia or osteoporosis: A systematic review. International Journal of Nursing Studies Advances. 2026; 10: 100456. https://doi.org/10.1016/j.ijnsa.2025.100456

[16] Glaser DL, Kaplan FS. Osteoporosis: definition and clinical presentation. Spine. 1997; 22: 12S–16S.

[17] World Health Organization. Regional Office for the Western Pacific. The Asia-Pacific perspective: redefining obesity and its treatment. Sydney: Health Communications Australia. 2000. Available at: https://apps.who.int/iris/handle/10665/206936 (Accessed: 12 October 2025).

[18] Eastell R, Rosen CJ, Black DM, Cheung AM, Murad MH, Shoback D. Pharmacological Management of Osteoporosis in Postmenopausal Women: An Endocrine Society* Clinical Practice Guideline. The Journal of Clinical Endocrinology and Metabolism. 2019; 104: 1595–1622. https://doi.org/10.1210/jc.2019-00221

[19] Salari N, Ghasemi H, Mohammadi L, Behzadi MH, Rabieenia E, Shohaimi S, et al. The global prevalence of osteoporosis in the world: a comprehensive systematic review and meta-analysis. Journal of Orthopaedic Surgery and Research. 2021; 16: 609. https://doi.org/10.1186/s13018-021-02772-0

[20] Clynes MA, Gregson CL, Bruyère O, Cooper C, Dennison EM. Osteosarcopenia: where osteoporosis and sarcopenia collide. Rheumatology (Oxford, England). 2021; 60: 529–537. https://doi.org/10.1093/rheumatology/keaa755

[21] Kurabayash T, Nagai K, Hayashi K, Yasui T, Takamatsu K, Ideno Y. Importance of changes in body mass index from adolescence to middle age as a risk factor for osteoporosis: the Japan Nurses' Health Study. Menopause (New York, N.Y.). 2026; 10.1097/GME.0000000000002740. https://doi.org/10.1097/GME.0000000000002740

[22] Chen Z, Yang Y, Shi X, Yang R, Fang W, Liang G, et al. Bone marrow-derived mesenchymal stem cells alleviate hepatic lipid metabolism disorders after scald injury: integrating liver transcriptome and metabolome. Stem Cell Research & Therapy. 2026; 17: 1. https://doi.org/10.1186/s13287-025-04774-9

[23] Chen YY, Wang WW, Yang L, Chen WW, Zhang HX. Association between lipid profiles and osteoporosis in postmenopausal women: a meta-analysis. European Review for Medical and

Pharmaceutical Sciences. 2018; 22: 1–9. https://doi.org/10.26355/eurrev_201801_14093

[24] Yang J, Kong G, Yao X, Zhu Z. Association between Serum Total Testosterone Level and Bone Mineral Density in Middle-Aged Postmenopausal Women. International Journal of Endocrinology. 2022; 2022: 4228740. https://doi.org/10.1155/2022/4228740

[25] Zhao X, Sun J, Xin S, Zhang X. Association between new anthropometric indices and osteoporosis in Chinese postmenopausal women- retrospective study based on hospitalized patients in China. Frontiers in Endocrinology. 2025; 16: 1535540. https://doi.org/10.3389/fendo.2025.1535540

[26] Schulz N, Lange U, Klemm P. The role of nutrition in osteoprotection. Orthopadie (Heidelberg, Germany). 2025; 54: 939–944. https://doi.org/10.1007/s00132-025-04729-1

[27] Gregson CL, Armstrong DJ, Avgerinou C, Bowden J, Cooper C, Douglas L, et al. The 2024 UK clinical guideline for the prevention and treatment of osteoporosis. Archives of Osteoporosis. 2025; 20: 119. https://doi.org/10.1007/s11657-025-01588-3

[28] Wong P, Chen W, Ewald D, Girgis C, Rawlin M, Tsingos J, et al. 2024 Royal Australian College of General Practitioners and Healthy Bones Australia guideline for osteoporosis management and fracture prevention in postmenopausal women and men over 50 years of age. The Medical Journal of Australia. 2025; 222: 472–480. https://doi.org/10.5694/mja2.52637

[29] Maloney-Saxon GL. Osteoporosis: What every nurse should know. Nursing. 2025; 55: 19–27. https://doi.org/10.1097/NSG.0000000000000179

[30] Muñoz-Garach A, García-Fontana B, Muñoz-Torres M. Nutrients and Dietary Patterns Related to Osteoporosis. Nutrients. 2020; 12: 1986. https://doi.org/10.3390/nu12071986