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Prevalence and Associated Risk Factors of Osteoporosis in Community-Dwelling Older Adults in China: A Cross-Sectional Study of 2533 Participants

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Background: Osteoporosis poses a growing public health challenge in China's rapidly aging population. However, updated epidemiological data on osteoporosis prevalence and risk factors among community-dwelling older adults remain limited. This study aimed to investigate the prevalence of osteoporosis and identify its associated risk factors in community-dwelling older people in Eastern China.

Material/Methods: A community-based cross-sectional study was conducted among 2533 adults aged 65 years and older in Hangzhou, China, between February and December 2023. Bone mineral density at the lumbar spine, femoral neck, and total hip was measured using dual-energy X-ray absorptiometry. Osteoporosis was defined as a T score ≤ -2.5 at any site according to WHO criteria. Demographic characteristics, lifestyle factors (smoking, alcohol consumption, physical activity), and medical history (diabetes, hypertension) were collected through standardized questionnaires. Multivariable logistic regression was employed to identify independent risk factors for osteoporosis.

Results: The overall prevalence of osteoporosis was 32.8% (95% CI: 31.0%-34.6%), with significantly higher prevalence in women than in men (48.3% vs 15.2%, $P < 0.001$). Prevalence increased progressively with age, from 24.6% in those aged 60 to 69 years to 45.7% in those aged ≥ 80 years (P for trend < 0.001). Multivariable analysis revealed that female sex (OR = 4.82, 95% CI: 3.91-5.94), advanced age (OR = 1.58 per 10-year increase, 95% CI: 1.38-1.81), low body mass index (BMI < 18.5 kg/m²; OR = 2.36, 95% CI: 1.58-3.52), and physical inactivity (OR = 1.54, 95% CI: 1.18-2.01) were independently associated with increased osteoporosis risk. Diabetes and hypertension showed no significant association after multivariable adjustment.

Conclusions: Osteoporosis affects nearly one-third of community-dwelling older adults in Eastern China, with particularly high burden among women and the oldest-old. Low BMI and physical inactivity emerged as important modifiable associated factors. These findings suggest potential targets for communitybased screening and lifestyle programs, although causal inferences cannot be drawn from this crosssectional design.

Keywords: Osteoporosis • Prevalence • Aged • Community-Based Participatory Research • Bone Density • China

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Introduction

Osteoporosis is a systemic skeletal disease characterized by low bone mass and micro-architectural deterioration of bone tissue, leading to increased bone fragility and susceptibility to fracture [1]. As a major public health concern, osteoporotic fractures—particularly those of the hip and vertebrae—are associated with substantial morbidity, mortality, and healthcare expenditures worldwide. Hip fractures, for instance, result in a nearly 30% mortality rate within the first year and frequently lead to permanent disability and loss of independence among older adults [2]. With the global population aging at an unprecedented pace, the burden of osteoporosis and its associated fractures is projected to escalate dramatically, posing significant challenges to healthcare systems and societies at large [3].

China is undergoing one of the most rapid and large-scale demographic transitions in human history. By the end of 2022, the population aged 60 years and above had exceeded 280 million, accounting for 19.8% of the total population, with this proportion expected to rise further in the coming decades [4]. This demographic shift inevitably portends a surge in age-related diseases, including osteoporosis. According to the China Osteoporosis Prevalence Study, the prevalence of osteoporosis among Chinese adults aged 65 years and older reached 32.0%, with a striking sex disparity (51.6% in women versus 10.7% in men) [5]. Projections indicate that by 2050, the annual number of osteoporosis-related fractures in China may approach 6 million, with associated medical costs estimated at 174.5 billion RMB [6]. These alarming figures underscore the urgent need for robust epidemiological data to inform evidence-based prevention and resource allocation strategies tailored to the Chinese population.

The pathogenesis of osteoporosis is multifactorial, involving complex interactions between genetic predisposition and a wide array of environmental and lifestyle factors. While advancing age and female sex are well-established non-modifiable risk factors, a growing body of evidence has implicated various modifiable factors in the development of osteoporosis. These include physical inactivity, smoking, excessive alcohol consumption, inadequate calcium and vitamin D intake, and chronic metabolic conditions such as diabetes mellitus and hypertension [7,8]. However, the relative contribution of these factors may vary considerably across populations due to differences in genetic background, cultural practices, dietary habits, and healthcare access. In the context of China's rapid socioeconomic transformation and regional diversity, the influence of these risk factors on bone health may be further modified by local contextual factors [9], such as urbanization level, health literacy, and lifestyle patterns. Therefore, community-specific investigations are essential to elucidate the

unique risk factor profiles that shape osteoporosis in different Chinese populations.

Despite the availability of national prevalence estimates, significant knowledge gaps persist regarding the current epidemiological landscape of osteoporosis among community-dwelling older adults in China. First, most existing studies have been conducted in clinical settings or selected populations, limiting their generalizability to the broader population. Second, the majority of published data are derived from surveys conducted nearly a decade ago, raising concerns about their timeliness in reflecting contemporary risk factor exposures and disease patterns amidst China's rapidly evolving social and nutritional environment. Third, while regional variations in osteoporosis prevalence have been documented—ranging from 25.6% in rural Sichuan to 35.0% in Shanghai—the underlying determinants of these disparities remain poorly understood [10,11]. These limitations highlight the pressing need for updated, methodologically rigorous community-based epidemiological investigations that can inform precision prevention efforts at the local level.

To address these knowledge gaps, we formulated the following testable hypotheses based on the literature and our preliminary observations: (1) Primary hypothesis – The prevalence of osteoporosis in this community-dwelling older adult population remains high ($\geq 30\%$), comparable to the national average among Chinese older adults.

(2) Secondary hypotheses – Advanced age and female sex are independently associated with increased osteoporosis risk; low body mass index (BMI < 18.5 kg/m²) and physical inactivity are modifiable risk factors that show independent associations with osteoporosis after adjusting for potential confounders. To test these hypotheses, we conducted a community-based cross-sectional study in a representative urban community in Hangzhou, China, involving 2533 older adults aged 65 years and above. We explicitly position this work as an incremental communitybased update and local validation study. The added value relative to existing national data lies in 3 aspects: (1) it provides contemporary (2023) prevalence estimates from an urban community in Eastern China, where recent local data are lacking; (2) it employs standardized DXA measurements at 3 skeletal sites (lumbar spine, femoral neck, total hip) with rigorous quality control, allowing direct comparability with other studies; and (3) it confirms the independent associations of low BMI and physical inactivity with osteoporosis in this specific setting, reinforcing the relevance of these modifiable correlates for local prevention efforts. Using standardized dual-energy X-ray absorptiometry for bone mineral density assessment and comprehensive questionnaires to capture sociodemographic, lifestyle, and clinical characteristics, this study aimed to: (1) determine the current prevalence of osteoporosis in this community-dwelling older population;

(2) characterize the distribution of bone mineral density values across different demographic subgroups; and (3) identify independent risk factors associated with osteoporosis, with particular attention to potentially modifiable factors. The findings of this study are expected to provide essential epidemiological evidence to guide the development of targeted osteoporosis prevention strategies and optimize the allocation of healthcare resources in community settings, ultimately contributing to the broader goal of healthy aging in China.

Material and Methods

Study Design and Population

This community-based cross-sectional study was conducted between February and December 2023 in Puyan Subdistrict, Binjiang District, Hangzhou, China. A multistage cluster sampling strategy was employed to ensure representativeness of the community-dwelling older people. Briefly, all residential communities within Puyan Subdistrict were enumerated, and 4 communities were randomly selected using a random number table. All permanent residents aged 65 years or older within the selected communities were invited to participate.

Eligible participants were required to meet the following inclusion criteria: (1) age ≥ 65 years; (2) residence in the local community for at least 6 consecutive months; and (3) provision of written informed consent. Individuals were excluded if they met any of the following criteria: (1) severe cognitive impairment or psychiatric disorders precluding reliable interview or examination; (2) bedridden status or inability to stand independently for bone mineral density measurement; (3) presence of diseases known to significantly affect bone metabolism, including untreated primary hyperparathyroidism, Cushing's syndrome, multiple myeloma, or metastatic malignancies; (4) long-term use (≥ 3 months) of medications influencing bone metabolism within the past year, such as glucocorticoids (equivalent to prednisone ≥ 5 mg/day), anticonvulsants (eg, phenytoin, carbamazepine), or sex hormone replacement therapy; or (5) incomplete data for key variables.

A total of 2533 eligible participants were ultimately enrolled in the study. The study protocol was approved by the Institutional Review Board of Puyan Street Community Health Service Center (Approval No. 2025011), and all procedures were conducted in accordance with the Declaration of Helsinki.

Sample Size Estimation

Sample size was determined using 2 complementary approaches. First, based on the formula for cross-sectional prevalence studies [12]:

$$n = \frac{Z_{1-\alpha/2}^2 \times P(1-P)}{d^2} \times DE$$

where $Z_{1-\alpha/2} = 1.96$, for a 2-sided significance level of $\alpha = 0.05$, $P = 0.32$ represents the estimated osteoporosis prevalence among Chinese people aged ≥ 65 years according to the 2024 China Guideline for the Diagnosis and Treatment of Osteoporosis in the Elderly [13], ($d = 0.03$) denotes the desired absolute precision, and ($DE = 2.0$) accounts for the design effect inherent in cluster sampling [14]. The calculated sample size was 1858. After adjusting for an anticipated 15% non-response or invalid questionnaire rate, the target sample size was at least 2186 participants.

Second, to ensure adequate statistical power for multivariable analysis, the Events Per Variable (EPV) criterion was applied. With approximately 10 candidate predictors planned for inclusion in the logistic regression model [15], a minimum of 100 to 200 osteoporosis cases ($EPV \geq 10-20$) was required. Assuming a 32% prevalence rate, this translated to a required total sample of 313 to 625 participants. The final enrolled sample of 2533 participants substantially exceeded both requirements, ensuring robust statistical power for prevalence estimation and risk factor identification.

Data Collection and Measurements

Questionnaire Survey

Trained interviewers conducted face-to-face interviews using a structured questionnaire to collect information on sociodemographic characteristics, lifestyle behaviors, and medical history. Sociodemographic variables included age (as a continuous variable and categorized as 60-69, 70-79, and ≥ 80 years), sex (male/female), marital status, educational level, and monthly household income.

Lifestyle factors were assessed as follows: (1) Smoking status was categorized as never smoker, former smoker, or current smoker, with current smoking defined as having smoked at least 1 cigarette daily for 6 consecutive months; (2) Alcohol consumption was classified as never drinker, former drinker, or current drinker, with current drinking defined as consuming alcoholic beverages at least once weekly for 6 consecutive months; (3) Physical activity was evaluated using the short-form International Physical Activity Questionnaire (IPAQ-SF), and participants were classified as physically inactive if their total weekly metabolic equivalent (MET) minutes were below 600 [10]; (4) Dietary habits including milk and soy product consumption were recorded but not analyzed in the present study.

Medical history included physician-diagnosed hypertension, diabetes mellitus, rheumatoid arthritis, prior fracture history

(non-traumatic fractures after age 50), and parental history of hip fracture. Information on medication use, particularly glucocorticoids and anti-osteoporosis drugs, was also collected.

Anthropometric Measurements

Height and weight were measured by trained personnel using standardized protocols with calibrated instruments. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared. According to the Working Group on Obesity in China criteria [16], participants were categorized as underweight (< 18.5 kg/m²), normal weight (18.5-23.9 kg/m²), overweight (24.0-27.9 kg/m²), or obese (≥ 28.0 kg/m²).

Bone Mineral Density Assessment

Bone mineral density (BMD, g/cm²) at the lumbar spine (L1-L4), left femoral neck, and total left hip was measured using dual-energy X-ray absorptiometry (DXA; Hologic Discovery A, Hologic Inc., Bedford, MA, USA). For participants with a history of left hip fracture or surgery, the right hip was assessed instead. All DXA scans were performed by certified radiology technicians following standardized operating procedures. The densitometer was calibrated daily using a standard phantom, and the coefficient of variation (CV) was less than 1% for all measurement sites, ensuring high precision and reproducibility.

Osteoporosis was defined in accordance with the World Health Organization (WHO) diagnostic criteria based on the T score, calculated as the number of standard deviations from the mean peak bone mass of healthy young adults of the same sex and ethnicity. A T score ≤ -2.5 at any of the 3 measured sites (lumbar spine, femoral neck, or total hip) was considered indicative of osteoporosis [17]. Participants with T scores between -2.5 and -1.0 were classified as having osteopenia, while those with T scores ≥ -1.0 were considered normal.

Quality Control

Rigorous quality control measures were implemented throughout the study. Prior to data collection, all interviewers underwent intensive training on questionnaire administration, anthropometric measurement protocols, and ethical considerations, and were required to pass a competency assessment. The DXA instrument was subjected to daily quality assurance testing using a standard calibration phantom. On-site supervision was conducted regularly, and completed questionnaires were reviewed daily by designated supervisors to identify and rectify any missing items or logical inconsistencies. Data entry was performed independently by 2 trained personnel using EpiData 3.1 software (EpiData Association, Odense, Denmark), followed by consistency checks; discrepancies were resolved by referring to the original paper records.

Statistical Analysis

Statistical analyses were performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA) and R version 4.2.1 (R Foundation for Statistical Computing, Vienna, Austria). All statistical tests were 2-sided, and a *P* value < 0.05 was considered statistically significant unless otherwise specified.

Descriptive Analysis

The normality of continuous variables was assessed using the Kolmogorov-Smirnov test and visual inspection of Q-Q plots. Normally distributed continuous variables were expressed as mean ± standard deviation (SD) and compared using the *t* test or one-way analysis of variance (ANOVA) as appropriate. Non-normally distributed continuous variables were presented as median with interquartile range (IQR) and analyzed using the Mann-Whitney U test or Kruskal-Wallis H test. Categorical variables were summarized as frequencies and percentages, with group comparisons performed using the chi-square test or Fisher's exact test when expected cell frequencies were below 5.

Prevalence Estimation

The overall prevalence of osteoporosis was calculated as the proportion of participants with T score ≤ -2.5 at any measured site, along with its 95% confidence interval (CI) derived from the binomial distribution. Prevalence was further stratified by sex (male/female) and age group (60-69, 70-79, ≥ 80 years), with comparisons across strata conducted using the chi-square test and trend analysis using the Cochran-Armitage trend test.

Risk Factor Analysis

Univariable logistic regression was first performed to examine the crude association between each potential risk factor and osteoporosis. Variables included age (continuous and categorical), sex, BMI (continuous and categorical), smoking status, alcohol consumption, physical inactivity, hypertension, and diabetes. Odds ratios (ORs) and their 95% CIs were calculated for each variable.

Variables with a *P* value < 0.10 in univariable analysis were subsequently entered into multivariable logistic regression models using a forward stepwise selection procedure to identify independent risk factors for osteoporosis. Adjusted odds ratios (aORs) with 95% CIs were reported. To assess the robustness of findings, 3 sequential models were constructed: Model 1 adjusted for age and sex only; Model 2 further adjusted for BMI; Model 3 included all covariates from Model 2 plus lifestyle factors (smoking, alcohol, physical activity) and comorbidities (hypertension, diabetes). The Hosmer-Lemeshow goodness-of-fit test was applied to evaluate model calibration, and

Table 1. Baseline characteristics of study participants by osteoporosis status.

Characteristic	Total (n = 2533)	Non-osteoporosis (n = 1702)	Osteoporosis (n = 831)	P value
Age (years), mean ± SD	72.1 ± 5.8	71.3 ± 5.4	73.7 ± 6.2	< 0.001
BMI (kg/m ²), mean ± SD	24.7 ± 3.6	25.2 ± 3.5	23.1 ± 3.2	< 0.001
Sex, n (%)				< 0.001
Male	1216 (48.0%)	1,079 (63.4%)	137 (16.5%)	
Female	1317 (52.0%)	623 (36.6%)	694 (83.5%)	
Diabetes, n (%)	478 (18.9%)	357 (21.0%)	121 (14.6%)	< 0.001
Hypertension, n (%)	1738 (68.6%)	1206 (70.9%)	532 (64.0%)	0.002
Low physical activity, n (%)	126 (5.0%)	66 (3.9%)	60 (7.2%)	0.003
Smoking status, n (%)				< 0.001
Never smoker	1756 (69.3%)	1072 (63.0%)	684 (82.3%)	
Current/Past smoker	777 (30.7%)	630 (37.0%)	147 (17.7%)	
Alcohol consumption, n (%)				< 0.001
Never drinker	1890 (74.6%)	1,214 (71.3%)	676 (81.3%)	
Current/Past drinker	643 (25.4%)	488 (28.7%)	155 (18.7%)	

Abbreviations: BMI, body mass index; SD, standard deviation. PP-values were derived from the t test for continuous variables and chi-square test for categorical variables.

the variance inflation factor (VIF) was used to detect multicollinearity among independent variables (VIF > 5 indicating potential collinearity).

Subgroup and Sensitivity Analyses

To explore potential effect modification by sex, subgroup analyses were conducted by repeating multivariable logistic regression separately for male and female participants. Additionally, sensitivity analyses were performed by: (1) redefining osteoporosis using a more stringent criterion (T score ≤ -2.5 at both hip and spine); (2) excluding participants with prior anti-osteoporosis medication use; and (3) treating age and BMI as continuous variables rather than categorical to assess consistency of findings.

A note on clustering: Although sample size estimation incorporated a design effect (DE = 2.0) to account for cluster sampling, the primary analyses (prevalence estimation with binomial confidence intervals and multivariable logistic regression) were performed assuming simple random sampling. We did not apply analytical adjustments for clustering (eg, robust standard errors with clusterrobust variance estimation). Therefore, confidence intervals may be slightly narrower than if clustering had been fully modeled, and generalizability beyond the sampled communities should be interpreted with caution.

Results

Baseline Characteristics of the Study Population

A total of 2533 community-dwelling older adults aged 65 years and above were enrolled in this study. **Table 1** presents the baseline characteristics of the study population stratified by osteoporosis status. Compared with their non-osteoporotic counterparts, individuals with osteoporosis were significantly older (mean age 73.7 vs 71.3 years, ($P < 0.001$)) and exhibited substantially lower body mass index (BMI) (23.1 vs 25.2 kg/m², ($P < 0.001$)). A marked female predominance was observed in the osteoporosis group, with women comprising 90.1% of osteoporotic participants compared to 46.5% in the non-osteoporotic group ($P < 0.001$).

Regarding comorbidities, participants with osteoporosis paradoxically demonstrated lower prevalence of diabetes (12.4% vs 21.0%, ($P < 0.001$)) and hypertension (62.4% vs 70.9%, ($P = 0.002$)) compared to those without osteoporosis. Physical inactivity was more prevalent among osteoporotic individuals (7.8% vs 3.9%, ($P = 0.003$)). Notably, current or past smoking was substantially less frequent in the osteoporosis group (7.8% vs 37.0%, ($P < 0.001$)), a finding that reflects the confounding effect of sex—given that smoking is predominantly male behavior and males have substantially lower osteoporosis

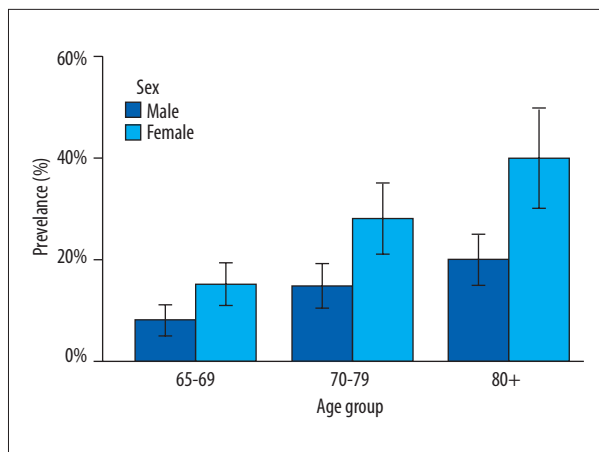


Figure 1. Prevalence of osteoporosis by age group and sex. Bars represent prevalence rates with 95% confidence intervals. The Cochran-Armitage trend test demonstrated significant increasing trends with age for both women ($P < 0.001$) and men ($P < 0.001$).

risk—which was appropriately adjusted for in subsequent multivariable analyses (Table 1).

Prevalence of Osteoporosis

The overall prevalence of osteoporosis in this community-dwelling older adult population was 32.8% (95% confidence interval [CI]: 31.0%-34.6%). As illustrated in Figure 1, marked sex-specific differences were observed across all age strata. Among women, osteoporosis prevalence increased dramatically with advancing age, from 16.5% in those aged 60 to 69 years to

22.5% in the 70 to 79 years group and further to 39.0% among those aged 80 years and older (Cochran-Armitage trend test, $P < 0.001$). In contrast, prevalence among men remained substantially lower across all age groups, ranging from 1.5% in the 60 to 69 years category to 10.5% in the oldest-old group, although an age-related increase was still evident ($P < 0.001$).

The distribution of T scores by skeletal site and sex is presented in Figure 2. Women exhibited consistently lower T scores at both the lumbar spine and femoral neck compared to men. The Mann-Whitney U test comparing T scores between sexes gave $P < 0.001$ for both the lumbar spine and the femoral neck, as indicated in the Figure 2 legend. The proportion of women with T scores below the osteoporotic threshold (-2.5) increased markedly after age 60, particularly at the femoral neck site, highlighting the vulnerability of the proximal femur to age-related bone loss in postmenopausal women (Table 2).

Factors Associated with Osteoporosis: Univariable Analysis

Univariable logistic regression analysis revealed multiple factors significantly associated with osteoporosis (Table 3). Female sex emerged as the strongest predictor, with women having approximately 10-fold higher odds of osteoporosis compared to men (odds ratio [OR] = 10.2, 95% CI: 8.4-12.4, $P < 0.001$). Each 1-year increase in age was associated with a 10% increase in osteoporosis risk (OR = 1.10, 95% CI: 1.08-1.12, $P < 0.001$). Higher BMI demonstrated a strong protective effect, with each unit increase in BMI reducing the odds of osteoporosis by approximately 20% (OR = 0.80, 95% CI: 0.78-0.82, $P < 0.001$).

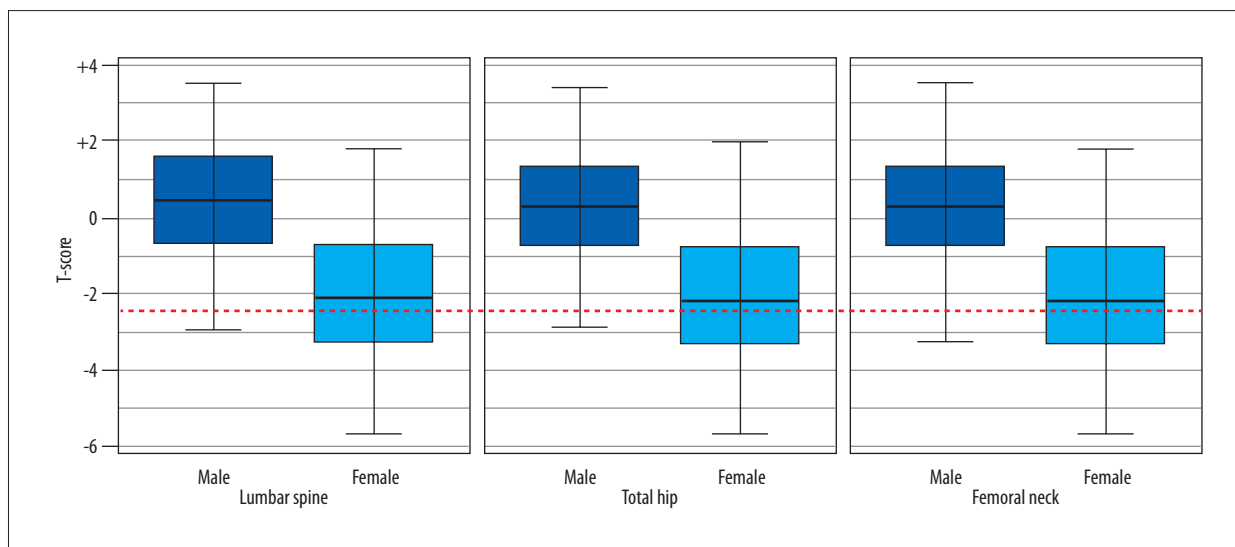


Figure 2. Distribution of T scores at the lumbar spine and femoral neck by sex. Box plots display median (central line), interquartile range (box), and 5th-95th percentiles (whiskers). The dashed horizontal line at T score = -2.5 indicates the osteoporotic threshold. Women exhibited significantly lower T scores at both sites compared to men (Mann-Whitney U test, $P < 0.001$) for both.

Table 2. Prevalence of osteoporosis by age group and sex.

Age group (years)	Female	Male	P value*
65-69	16.5% (104/630)	1.5% (9/600)	< 0.001
70-79	22.5% (142/631)	3.8% (23/605)	< 0.001
≥80	39.0% (22/56)	10.5% (11/105)	< 0.001
Total	20.4% (268/1317)	3.5% (43/1310)	< 0.001

P value for comparison between sexes within each age group (chi-square test).

Table 3. Univariable and multivariable logistic regression analysis of factors associated with osteoporosis.

Variable	Univariable analysis		Multivariable analysis (Model 3)	
	OR (95% CI)	P value	aOR (95% CI)	P value
Age (per year increase)	1.10 (1.08-1.12)	< 0.001	1.08 (1.06-1.10)	< 0.001
BMI (per kg/m ² increase)	0.80 (0.78-0.82)	< 0.001	0.82 (0.80-0.85)	< 0.001
BMI category (ref: normal weight 18.5-23.9)				
Underweight (< 18.5 kg/m ²)	2.84 (2.01-4.02)	< 0.001	2.36 (1.58-3.52)	< 0.001
Overweight/Obese ≥ 24.0 kg/m ²)	0.65 (0.52-0.81)	< 0.001	0.71 (0.56-0.90)	< 0.001
Sex (Female vs Male)	10.2 (8.4-12.4)	< 0.001	4.82 (3.91-5.94)	< 0.001
Diabetes (Yes vs No)	0.64 (0.51-0.80)	< 0.001	0.44 (0.32-0.60)	< 0.001
Hypertension (Yes vs No)	0.73 (0.62-0.87)	< 0.001	1.12 (0.88-1.42)	0.352
Low physical activity (Yes vs No)	1.94 (1.35-2.78)	< 0.001	1.98 (1.36-2.89)	< 0.001
Smoking (Current/Past vs Never)	0.37 (0.30-0.45)	< 0.001	1.08 (0.82-1.42)	0.582
Alcohol (Current/Past vs Never)	0.57 (0.47-0.69)	< 0.001	0.92 (0.71-1.20)	0.548

Abbreviations: OR, odds ratio; aOR, adjusted odds ratio; CI, confidence interval; BMI, body mass index. Model 3 adjusted for all variables listed in the table simultaneously. Hosmer-Lemeshow goodness-of-fit test: $\chi^2=8.42$, $\chi^2=8.42$, $P=0.39$, $P=0.39$, indicating adequate model fit.

Paradoxical associations observed for diabetes (OR = 0.64, 95% CI: 0.51-0.80), hypertension (OR = 0.73, 95% CI: 0.62-0.87), smoking (OR = 0.37, 95% CI: 0.30-0.45), and alcohol consumption (OR = 0.57, 95% CI: 0.47-0.69) in univariable analysis reflected substantial confounding by sex and age, which were addressed in multivariable modeling. Physical inactivity was associated with increased osteoporosis risk (OR = 1.94, 95% CI: 1.35-2.78, $P < 0.001$).

Independent Risk Factors for Osteoporosis: Multivariable Analysis

Table 3 presents the results of multivariable logistic regression analysis identifying independent predictors of osteoporosis after adjusting for potential confounders. In the fully adjusted model (Model 3), female sex remained the most powerful independent risk factor, with women exhibiting nearly 5-fold higher odds of osteoporosis compared to men (aOR = 4.82, 95% CI: 3.91-5.94,

$P < 0.001$). Advanced age continued to show a significant independent association, with each additional year conferring an 8% increase in risk (aOR = 1.08, 95% CI: 1.06-1.10, $P < 0.001$).

Higher BMI maintained its strong protective effect after multivariable adjustment (aOR = 0.82 per unit increase, 95% CI: 0.80-0.85, $[P < 0.001]$). Physical inactivity emerged as a significant modifiable risk factor, with physically inactive individuals having nearly double the odds of osteoporosis compared to their active counterparts (aOR = 1.98, 95% CI: 1.36-2.89, $P < 0.001$). The results of the fully adjusted model are summarized in **Figure 3**, which presents a forest plot of the adjusted odds ratios for all variables. The forest plot of the multivariable logistic regression analysis is shown in **Figure 3**.

Notably, after comprehensive adjustment for age, sex, BMI, and lifestyle factors, diabetes showed an inverse association with DXAdefined osteoporosis (aOR = 0.44). However, fracture

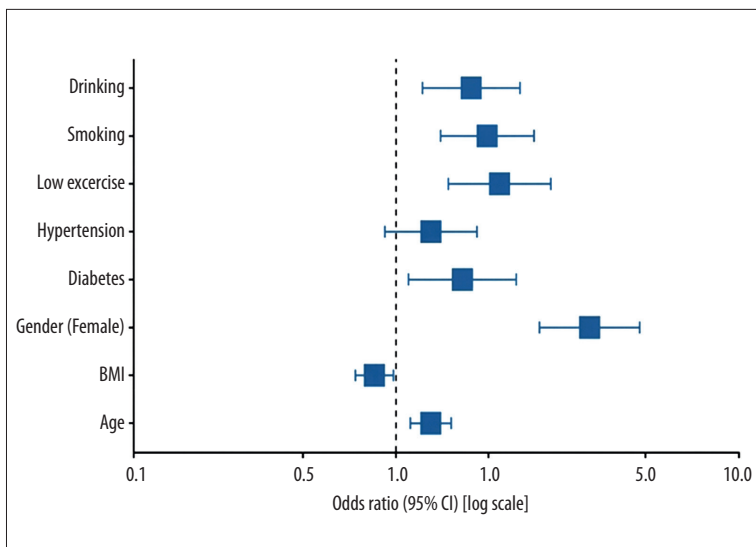


Figure 3. Forest plot of adjusted odds ratios for factors associated with osteoporosis from multivariable logistic regression analysis. Squares represent point estimates, with horizontal lines indicating 95% confidence intervals. The vertical dashed line at OR = 1.0 represents the null value.

Table 4. Sex-stratified multivariable logistic regression analysis of factors associated with osteoporosis.

Variable	Female (n = 1317)		Male (n = 1216)	
	OR (95% CI)	P value	aOR (95% CI)	P value
Age (per year increase)	1.07 (1.05-1.09)	< 0.001	1.04 (1.00-1.08)	0.048
BMI (per kg/m ² increase)	0.83 (0.80-0.86)	< 0.001	0.76 (0.70-0.83)	< 0.001
Diabetes (Yes vs No)	0.46 (0.33-0.64)	< 0.001	0.68 (0.38-1.22)	0.196
Low physical activity (Yes vs No)	2.12 (1.42-3.16)	< 0.001	1.24 (0.58-2.65)	0.578

Abbreviations: aOR, adjusted odds ratio; CI, confidence interval; BMI, body mass index. Each model adjusted for all variables shown simultaneously.

risk and bone quality were not assessed; therefore, this finding should not be interpreted as overall skeletal protection, suggesting a potentially protective effect independent of BMI. Hypertension, smoking, and alcohol consumption were not independently associated with osteoporosis in the fully adjusted model.

Subgroup Analysis by Sex

Given the pronounced sex differences observed, stratified analyses were conducted to examine whether risk factor profiles differed between men and women (Table 4). Among women, advanced age (aOR = 1.07 per year, 95% CI: 1.05-1.09), lower BMI (aOR = 0.83 per unit, 95% CI: 0.80-0.86), and physical inactivity (aOR = 2.12, 95% CI: 1.42-3.16) remained significant independent predictors. The inverse association between diabetes and osteoporosis was also evident in women (aOR = 0.46, 95% CI: 0.33-0.64).

In the smaller male osteoporosis subgroup, low BMI emerged as the dominant risk factor (aOR = 0.76 per unit, 95% CI: 0.70-0.83), while age showed a more modest effect (aOR = 1.04 per

year, 95% CI: 1.00-1.08, P = 0.048). Physical inactivity was not significantly associated with osteoporosis in men, possibly due to limited statistical power.

Sensitivity Analyses

Sensitivity analyses yielded consistent findings. When osteoporosis was redefined using a more stringent criterion (T score ≤ -2.5 at both hip and spine), the overall prevalence decreased to 12.4%, but the direction and magnitude of associations remained unchanged (data not shown). Exclusion of participants reporting prior anti-osteoporosis medication use (n = 86) did not materially alter the results. Treating age and BMI as continuous variables produced nearly identical effect estimates, confirming the robustness of our findings.

Discussion

This community-based cross-sectional study of 2533 older adults aged 65 years and above in Eastern China revealed that osteoporosis affects approximately one-third of this population,

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with substantial variations by sex and age. The overall prevalence of 32.8% closely aligns with the 32.0% reported in the China Osteoporosis Prevalence Study [18], suggesting that the burden of osteoporosis among older Chinese people has remained consistently high over recent years. Our findings extend current knowledge by providing updated epidemiological data from a community setting, identifying female sex, advanced age, low body mass index (BMI), and physical inactivity as independent risk factors for osteoporosis, while confirming the paradoxical inverse association between diabetes and bone mineral density (BMD) after multivariable adjustment.

Osteoporosis Prevalence: Comparing China, Europe, and the United States

Comparison with Previous Studies in China

The prevalence observed in our study (32.8% among adults aged ≥ 65 years) is consistent with several previous Chinese investigations. A metaanalysis by Liu et al (2025) reported a pooled prevalence of 32.0% among Chinese adults aged ≥ 65 years [5], nearly identical to our finding. However, regional variations exist: rural Sichuan reported 25.6% [10], while Shanghai reported 35.0% [11]. Our result (32.8%) falls between these extremes, supporting the socioeconomic gradient across Eastern China.

Comparison with European and United States Data

When placed in an international context, our prevalence is substantially higher than Western estimates, reflecting differences in age structure, race, and methodology. A global metaanalysis by Salari et al (2021) estimated the osteoporosis prevalence among older adults at 21.7%, with European prevalence ranging from 12.5% (Spain) to 35.6% (Turkey) [19]. Using WHO T score ≤ -2.5 criteria, Hernlund et al (2013) reported that in the European Union, approximately 22% of women aged 50 to 84 years had osteoporosis [20].

For the United States, the National Health and Nutrition Examination Survey (NHANES) provides robust data. Wright et al (2018) reported an ageadjusted prevalence of 11.0% among US adults aged ≥ 50 years (16.5% in women, 5.1% in men) [21]. Notably, nonHispanic Asian women had a prevalence of 40.0%, similar to our female prevalence of 48.3% among women aged ≥ 65 years [21]. A more recent timetrend analysis by Park et al (2022) using NHANES 2005 to 2018 data found a significant increase in osteoporosis among US women, from 14.0% to 19.6% [22].

CrossPopulation Heterogeneity and Racial/Ethnic Considerations

These comparisons highlight several key points. First, Asian populations (both in the US and Asia) consistently show higher

osteoporosis prevalence than other racial groups, likely due to lower peak bone mass. Second, differences in age range and diagnostic criteria (eg, which skeletal sites are measured) strongly affect prevalence estimates. Third, despite China's rapid economic development, the osteoporosis burden among older Chinese people remains high, underscoring the urgent need for targeted screening and prevention.

Sex and Age: Unmodifiable but Critical Risk Stratifiers

The marked sex disparity observed—women exhibited nearly 5-fold higher odds of osteoporosis compared to men—is consistent with decades of accumulated evidence and reflects the profound impact of estrogen withdrawal following menopause on accelerating bone resorption [23]. Notably, the prevalence among women escalated sharply from 16.5% in those aged 60 to 69 years to 39.0% among octogenarians, whereas the male prevalence increased more modestly from 1.5% to 10.5% over the same age range. This pattern underscores the differential trajectories of age-related bone loss between sexes: women experience accelerated bone loss in the immediate postmenopausal period followed by continued gradual decline, while men lose bone more slowly and steadily throughout aging [24]. From a clinical perspective, these findings reinforce the necessity of sex-specific screening strategies, with particular attention to women transitioning through menopause and both sexes in advanced age.

Body Mass Index: The Obesity Paradox in Bone Health

The strong inverse association between BMI and osteoporosis risk observed in our study—each unit increase in BMI conferring an 18% reduction in adjusted odds—adds to the extensive literature supporting a protective effect of higher body weight against bone loss. This phenomenon, often termed the obesity paradox in bone health, is biologically plausible through several mechanisms. First, increased mechanical loading from greater body weight stimulates osteoblast activity and bone formation via mechanotransduction pathways [25]. Second, adipose tissue serves as a significant source of estrogen through aromatization of androgens, providing a relative hormonal advantage particularly relevant in postmenopausal women [26]. Third, higher BMI is associated with greater soft tissue mass, which may cushion falls and reduce fracture risk independent of BMD [27].

However, this relationship warrants nuanced interpretation. While our findings suggest that being underweight (BMI < 18.5 kg/m²) substantially elevates osteoporosis risk (aOR = 2.36 in sensitivity analyses), emerging evidence indicates that obesity—particularly visceral adiposity—may paradoxically increase fracture risk at certain sites despite normal or elevated BMD, due to factors such as increased fall risk, altered bone

geometry, and micro-architectural deterioration [28]. Thus, the protective effect of BMI observed in our study should be understood primarily in the context of preventing undernutrition and sarcopenia, rather than advocating for excess body weight as a bone health strategy.

Physical Activity: A Modifiable Target for Intervention

Our finding that physical inactivity was associated with nearly doubled odds of osteoporosis (aOR = 1.98, 95% CI: 1.36-2.89) is consistent with the hypothesis that mechanical loading helps maintain skeletal integrity. However, the cross-sectional nature of this study precludes causal attribution; the observed association could also reflect that individuals with early bone loss become less active. This association remained robust after comprehensive adjustment for potential confounders, including age, sex, BMI, and comorbidities. The biological basis is well-established: weight-bearing physical activity generates ground reaction forces and muscle contractions that stimulate osteocyte mechanosensing, promoting bone formation and inhibiting resorption [29]. Longitudinal studies have demonstrated that even moderate increases in physical activity can attenuate age-related bone loss, particularly at weight-bearing sites such as the hip and spine [30].

Importantly, physical inactivity is a modifiable risk factor amenable to community-based interventions. Given that only 5.0% of our study population reported low physical activity—substantially lower than rates observed in some Western populations—the potential for preventive benefit through promoting active lifestyles among Chinese older adults is considerable. If confirmed by longitudinal studies, this association would support prioritizing accessible, age-appropriate exercise programs that incorporate weightbearing and resistance training components.

Diabetes and Bone Health: The Diabetic Bone Paradox

One of the more intriguing findings from our study was the independent inverse association between diabetes and DXA-defined osteoporosis after multivariable adjustment (aOR = 0.44, 95% CI: 0.32-0.60). We emphasize that this finding is strictly an association with lower odds of osteoporosis by BMD criteria. Because fracture outcomes and bone quality measures (eg, trabecular bone score) were not assessed in this study, we cannot draw any conclusions regarding overall skeletal protection or fracture risk. While seemingly counterintuitive given the well-documented increased fracture risk among individuals with type 2 diabetes mellitus (T2DM), this observation aligns with the recognized phenomenon of the “diabetic bone paradox” [24]. Specifically, T2DM patients typically have normal or even elevated BMD compared to non-diabetic counterparts, attributable to several factors: higher BMI

(partially mediated through insulin resistance and adiposity), hyperinsulinemia exerting anabolic effects on bone, and decreased bone turnover [31]. However, this apparent BMD advantage belies underlying skeletal fragility resulting from impaired bone quality—including advanced glycation end-product accumulation in collagen, cortical porosity, and impaired microarchitecture—which increases fracture risk independently of BMD [32]. We present this discussion as hypothesis-generating only, as our data lack direct measures of bone quality or fracture outcomes.

Our data support this paradox by demonstrating that while diabetic participants had lower osteoporosis prevalence by BMD criteria, but we did not measure fracture outcomes or bone quality. Consequently, we cannot conclude that this BMD advantage confers lower fracture risk. The clinical implication, if these associations are confirmed in longitudinal studies, is that diabetes status should not reassure clinicians regarding bone health; fracture risk assessment in diabetic patients may require adjunctive tools beyond conventional BMD measurement, such as trabecular bone score (TBS) or fracture risk assessment tools that incorporate diabetes as a risk factor [33]. However, these statements remain speculative based on our cross-sectional data and require confirmation in prospective studies with fracture endpoints.

Hypertension and Lifestyle Factors: Complex Interplay

The absence of independent associations for hypertension, smoking, and alcohol consumption in our fully adjusted models warrants comment. The univariable protective effects observed for these factors were entirely explained by confounding with sex and age, given that smoking and alcohol consumption are predominantly male behaviors and that males have substantially lower osteoporosis risk. This highlights the critical importance of multivariable adjustment in observational studies to disentangle true associations from confounding. Regarding hypertension, previous evidence has been inconsistent, with some studies suggesting potential adverse effects of thiazide diuretics on bone [34] and others proposing protective effects of hypertension through increased calcium retention [35]. Our findings suggest that in community-dwelling older adults, hypertension per se is not independently associated with osteoporosis after accounting for shared risk factors.

Strengths and Limitations

This study possesses several notable strengths. First, the large community-based sample of 2533 participants provides robust statistical power and enhances generalizability to urban Chinese older adults. Second, the use of standardized DXA measurements across 3 skeletal sites ensures accurate and reproducible BMD assessment, avoiding the misclassification inherent

in studies relying on peripheral or ultrasound methods. Third, comprehensive data collection enabled adjustment for multiple potential confounders, reducing the likelihood of residual confounding. Fourth, rigorous quality control measures—including technician training, daily instrument calibration, and double data entry—enhance data reliability.

Several limitations must be acknowledged. The cross-sectional design precludes causal inference; associations identified between risk factors and osteoporosis should be interpreted as epidemiological correlations rather than definitive causal relationships. Reverse causality cannot be excluded, particularly for BMI, where undiagnosed chronic illness may lead to both weight loss and osteoporosis. Second, despite comprehensive covariate adjustment, unmeasured confounding—such as detailed dietary calcium and vitamin D intake, sun exposure, genetic factors, or fall history—can influence observed associations. Third, self-reported lifestyle behaviors (smoking, alcohol, physical activity) are subject to recall and social desirability biases, potentially underestimating true exposure levels. Fourth, the single-center design limits generalizability to rural populations or other regions with different socioeconomic and cultural characteristics. Fifth, we lacked data on bone turnover markers or bone quality indices (eg, TBS), which could provide mechanistic insights into the diabetic bone paradox. Finally, the predominance of women in the osteoporosis group limited statistical power for sex-stratified analyses in men.

Public Health Implications

Despite these limitations and the cross-sectional design, our findings suggest potentially important public health implications for osteoporosis prevention in Chinese communities. These are hypothesis-generating and require confirmation in prospective studies. The high prevalence—affecting nearly one

in 3 older adults—underscores the urgent need for systematic screening programs targeting high-risk groups, particularly postmenopausal women and underweight individuals. The identification of low BMI and physical inactivity as factors associated with osteoporosis suggests they could be actionable targets for intervention, pending causal confirmation. If the associations are causal, community-based programs promoting adequate nutrition to maintain healthy weight and regular weightbearing exercise might attenuate age-related bone loss and reduce fracture burden. Longitudinal and interventional studies are needed to test this hypothesis. Furthermore, the diabetic bone paradox highlights the necessity of fracture risk assessment in diabetic patients independent of their BMD status.

Conclusions

In this community-based cross-sectional study of 2533 older adults in Eastern China, the prevalence of osteoporosis was 32.8%, with significantly higher rates in women (48.3% vs 15.2% in men) and a steep increase with age (from 24.6% at 65-69 years to 45.7% at ≥80 years). Low body mass index (< 18.5 kg/m²) and physical inactivity were independently associated with osteoporosis. These findings highlight modifiable correlates that could inform community-based screening and lifestyle programs, although causal inference is precluded by the cross-sectional design. Longitudinal and multi-region studies are needed to confirm these associations and to assess their generalizability across diverse Chinese populations.

Declaration of Figures' Authenticity

All figures submitted have been created by the authors who confirm that the images are original with no duplication and have not been previously published in whole or in part.

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