BMC Geriatrics

RESEARCH

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Osteoporosis risk and its association with all-cause and cause-specific mortality among the elderly: a 16-year nationwide cohort study

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Abstract

Background Aged osteoporosis poses a significant threat to the well-being and longevity of older individuals, yet evidence regarding the relationship between osteoporosis risk and mortality among the elderly population in Asia remains unknown.

Aims Our study aimed to investigate associations between osteoporosis risk and all-cause mortality, as well as cause-specific mortality, among the Chinese elderly population.

Methods Pooled data from the Chinese Longitudinal Healthy Longevity Survey (CLHLS) conducted between 2002 and 2018 were utilized to analyze the associations between osteoporosis risk and all-cause, heart disease, cardiovascular disease (CVD), respiratory disease, and cancer mortality. Cox proportional hazards models were employed for this analysis. Osteoporosis risk was assessed using the Osteoporosis Self-Assessment Tool for Asians (OSTA). Restricted cubic spline (RCS) functions were applied to explore the nonlinear relationship between OSTA and mortality. The robustness of the Cox models was evaluated through internal verification, subgroup analyses, and sensitivity analyses.

Results A total of 12,711 elderly individuals aged ≥ 65 years were included for analysis at baseline. During a 16-year follow-up, 7,963 individuals in the cohort were identified as deceased. Compared to those with low osteoporosis risk, elderly individuals with high osteoporosis risk demonstrated a significantly elevated risk of all-cause, heart disease, CVD, respiratory disease and cancer mortality. The relationship between OSTA level and all-cause and cause-specific mortality exhibited a significant L-shaped pattern.

Conclusions The risk of osteoporosis is independently associated with the prediction of mortality. The OSTA may serve as a suitable predictor for mortality related to osteoporosis among the Asian population.

Keywords Osteoporosis risk, OSTA, All-cause mortality, Cause-specific mortality, CLHLS

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Introduction

Osteoporosis is a prevalent and progressive condition characterized by reduced bone mass and microstructure, resulting in an increased vulnerability to fractures and mortality [1–2]. Recent data suggests that as of 2018, there were approximately 10.9 million men and 49.3 million women affected by osteoporosis in China [3]. The prevalence of osteoporosis among individuals aged over 65 has significantly risen in China over the past decade. Consequently, addressing fragility fractures and preventing osteoporosis has become a priority for the elderly population in China [4]. The disease burden of osteoporosis-related fractures in China accounted for approximately 18.75% of the global DALYs (Disability-Adjusted Life Years) number, reaching around 1.83 million in 2019 [5]. Previous projections from the 1990s estimated that by the year 2050, there would be between 4.5 and 6.2 million elderly patients suffering from hip fractures related to osteoporosis worldwide, with half originating from Asia [6].

Several epidemiological studies involving Caucasian populations have assessed the relationships between osteoporosis/bone mineral density (BMD) and both all-cause and cause-specific mortality. However, there continues to be ongoing debate regarding the association between BMD across various skeletal sites and its ability to predict both all-cause and cause-specific mortality even at present [7–18]. Although BMD testing is widely recognized as the definitive method for diagnosing osteoporosis, it frequently faces challenges related to limited sample sizes and delays in implementing preventive measures against this condition. The evaluation of BMD has conventionally depended on dual-energy X-ray absorptiometry (DXA); however, its high expenses combined with restricted accessibility present obstacles given that China has only 0.46 DXA systems per million residents [19].

The OSTA is a simple yet effective clinical risk assessment tool specifically designed for the Asian population, aiming to early detect osteoporosis and predict fracture risk [20]. The study employed the OSTA, a cost-effective screening method that has been extensively validated and widely applied in clinical practice for assessing osteoporosis risk among Asian populations, such as Chinese [21–22], South Koreans [23], Malaysians [24], Indians [25], and Filipinos [26]. Although initially used to assess osteoporosis risk in postmenopausal women, subsequent studies have demonstrated that OSTA is also applicable for elderly men [20, 27–28]. The OSTA index demonstrated better performance than other indices, exhibiting a high sensitivity of 91%, moderate specificity of 45%, and an area under the curve (AUC) value of 0.79 at the cut-off of -1 in the original development datasets [29]. To a certain extent, OSTA may serve as a compensatory measure for the role of BMD testing in the early detection of osteoporosis, and even in the prediction of osteoporotic fractures and mortality.

The objective of this study was to investigate the association between osteoporosis risk and OSTA level with the risk of all-cause and cause-specific mortality among the elderly Chinese population, using data from a national, large-scale, and long-term survey.

Materials and methods

Study design and participants

The CLHLS is one of the world's largest surveys on the elderly population, encompassing 8 waves of in-depth surveys conducted by the Research Center for Healthy Aging and Development at Peking University/National Development Academy from 1998 to 2018. The survey employed a multistage, stratified cluster sampling design to recruit participants from 22 out of the 31 provinces in China, covering approximately 85% of the total population. A comprehensive account of the CLHLS procedures has been previously published [30–31]. The data from 2002, 2005, 2008, 2011, 2014, and 2018 were included in our study. We excluded the surveys conducted in 1998 and 2000 as they solely encompassed participants aged over 80 years old. This study focused on participants aged over 65 years old who completed the body weight assessment for analysis.

The CLHLS study received ethical approval from the Institutional Review Board (IRB) of Peking University (IRB00001052-13074). The survey procedures were conducted in accordance with the guidelines outlined in the Declaration of Helsinki. Written informed consent was obtained from all participants.

Definition of osteoporosis risk

As stated in the original research, the Osteoporosis Self-Assessment Tool for Asians (OSTA) was calculated based on age and body weight using the following formula: OSTA = (Body weight [kilogram] - age [years]) × 0.2 [29]. Decimal digits were then disregarded. Individuals with an OSTA score of less than − 4 were categorized as high risk, those with a score between >-4 and − 1< were classified as moderate risk, and individuals with a score greater than − 1 were considered low risk. A brief systematic review was conducted by searching PubMed with "Osteoporosis Self-Assessment Tool for Asians" as "MeSH Terms" in either the title or abstract, which revealed 92 publications (updated 30/6/2024). As we are aware, bone mineral density (BMD) measured by DXA currently serves as the gold standard for diagnosing osteoporosis. Finally, we included 20 studies published in English that compare the effectiveness of OSTA and BMD in detecting osteoporotic conditions within Asia. These studies, including meta-analyses, originated from

diverse Asian populations such as Chinese, Singaporeans, South Koreans, Thais, Malaysians, Indians, and Filipinos.

The risk of osteoporosis was determined by calculating the mean OSTA score from the first three waves of surveys conducted in 2002, 2005, and 2008. Weight measurements were obtained by trained interviewers adhering to standardized measurement protocols and utilizing calibrated scales. The difference between the interview date and birth date recorded on participants' identification cards was used to determine their true age.

Definition of mortality

The primary outcome of interest in this study was all-cause mortality. During the process of CLHLS, different causes of mortality were recorded based on ICD (International Classification of Diseases) codes and initially categorized into heart diseases, CVD, respiratory diseases, and cancer across all surveys as the secondary outcomes of our study. The dates of death were collected either from officially issued death certificates or through interviews with close family members or village doctors when available [30–31]. Previous studies have demonstrated the high quality of the CLHLS mortality data [32–34]. Duration of follow-up was defined as the time between the date interviewed in 2002 and the occurrence of outcomes or until 2018. In case a participant missed a follow-up visit, their survival time was calculated as the interval between their interview date in 2002 and the missed visit date. All time measurements are accurate to within a month.

Definition of covariates

Covariates were selected as potential confounders due to their influence on the causal pathway between exposures and outcomes. Demographic characteristics encompassed gender, residential category, smoking status, drinking status, physical activity level, educational attainment, and physical measurements (systolic blood pressure (SBP) and diastolic blood pressure (DBP)). Socioeconomic factors included financial condition, marital status, self-reported quality of life, and medical service utilization. Dietary habits involved the frequency of daily consumption of fresh fruits, vegetables, meat, fish, eggs, sugar and tea.

Trained interviewers collected all covariates using standardized questionnaires in each wave survey [42–44]. The category of residence was classified as urban (city) or rural (town and rural). Smoking status, drinking status, and physical activity were assessed through similar questions asking whether the participant currently smokes, drinks, or exercises. Educational level was categorized as low (< 9 years) or high (≥ 9 years) based on schooling years. Financial condition was interviewed by the question "Are all financial sources enough for your life?", and the answers were recorded as yes or no. Marital status was dichotomized into couple and single (separated, divorced, widowed, or never married) at the time of interview. Self-reported quality of life was merged into good condition versus so-so/bad condition. Medical service was interviewed by the question "Get adequate medical service at present?", and the answers were recorded as yes or no. A similar food frequency questionnaire was used to collect data on food consumption across all wave surveys with seven major food groups surveyed including fruits, vegetables, meat, fish, eggs, sugar and tea; answers were classified into three types: almost every day, occasionally and rarely/never.

The history of diseases was documented based on the hospital diagnosis records. Two steps were followed in this section of the questionnaire. Firstly, question "Did you suffer from diabetes/heart disease/respiratory disease/cardiovascular disease/cancer?" to primarily identify if the participants suffered the diseases. The second question "Was your disease diagnosed by hospital?" was used to confirm if their disease had been diagnosed by a hospital. Based on the responses received, we recorded double "yes" as yes and otherwise as no.

Statistical analysis

The descriptive statistics of baseline characteristics are presented according to the risk of osteoporosis. Continuous variables are reported as means with a 95% confidence interval (CI). Categorical variables are displayed as frequencies and percentages. One-way ANOVA analyses were employed for comparing differences in continuous variables. Chi-square tests were used for categorical variables.

Cox proportional hazard regression models were utilized to calculate the hazard ratios (HRs) and 95% CIs in the analyses. The backward stepwise regression method was employed to screen for statistically significant covariates in both univariable and multivariable models, which were included in the final models for analysis. To ensure model robustness, all participants were randomly divided into training and testing cohorts (7:3) for internal validation of multivariable Cox models. Final models adjusted for potential confounders were used to determine associations between osteoporosis risk and mortality from all-cause, heart disease, cardiovascular disease (CVD), respiratory disease, cancer, and other causes. ROC (receiver operating characteristic) curves were constructed with AUC calculated to assess each model's ability to predict mortality. AUC values greater than 0.6 are considered high level fits. Sex-specific HRs with 95% CIs were used to explore relationships between osteoporosis risk and mortality.

Restricted cubic spline (RCS) functions were used to investigate the nonlinear relationship between OSTA and

all-cause, heart disease, CVD, respiratory disease, cancer, and other cause mortality stratified by sex [35–36]. The final cox models and confounders were employed in this analysis to explore the nonlinear association. Consistent with previous research recommendations, we selected the median OSTA as the reference value for all analyses of nonlinear association. The fit of nonlinear curves was optimized when five knots were incorporated into the models, this approach prevented accuracy reduction due to over-fitting [37].

In order to further validate the robustness of the correlation between OSTA and mortality, we conducted the subgroup analysis by categorizing all potential covariates and the sensitive analysis by excluding part of participants. This comprehensive approach was employed to reevaluate the association between osteoporosis risk and both all-cause mortality as well as cause-specific mortality. By incorporating various factors that could potentially impact the relationship between OSTA and mortality, our aim was to provide a more precise and dependable estimation of this association.

All analyses were performed using R software version 4.3.1, and statistical significance was determined at a two-tailed p-value of less than 0.05.

Results

Descriptive analyses

In the 2002 CLHLS study, a total of 16,064 participants aged ≥ 65 years were enrolled. Due to the increased mortality risk among individuals over 100 years old, we excluded 3,353 elderly participants in this age group. The rate of missing data was below 3% and was addressed using multiple imputation techniques. Ultimately, our analysis included a sample size of 12,711 elderly participants with an average baseline age of 82.7 (95% CI: 82.6–82.9) years; out of these, there were 6,115 (48.1%) males and 6,596 (51.9%) females. Table 1 presents the characteristics of the study population. Over a 16-year follow-up period, we identified a total of 7,963 deaths within the cohort: specifically, there were 920 deaths attributed to heart diseases, 933 cases accounted for CVD-related fatalities, respiratory diseases caused 915 deaths, cancer resulted in 640 fatalities, while other causes led to 4555 deaths. Please refer to Fig. 1 for further details on the process.

Assessment of Cox proportional hazard regression models

The association between OSTA and all-cause mortality was explored, with frequent consumption of meat and eggs as well as educational level being excluded from the final models. Other factors were included in the final model after screening covariates using the backward stepwise regression method. The formula for the model of all-cause mortality is summarized as follows:

$$
\begin{aligned}
h\left(t\right) = h(t_0) * exp(&b_1(OSTA) + b_2(smoke) + \\
&b_3(drink) + b_4(residence) + b_5(exercise) + \\
&b_6(blood\,pressure) + b_7(financial\,condition) + \\
&b_8(marriage\,status) + b_9(quality\,of\,life) + \\
&b_{10}(medical\,service) + b_{11}(fruits) + \\
&b_{12}(vegetables) + b_{13}(fish) + \\
&b_{14}(sugar) + b_{15}(tea))
\end{aligned}
$$

where, t represents the survival time; $h(t)$ is the hazard function determined by a set of covariates; the coefficients (b_1, b_2,..., b_{15}) measure the effect of covariates; $h(t_0)$ is the baseline hazard. The similar screening processes were used into all models of exploration of OSTA and cause-specific mortality.

During the primary internal verification process, there were no significant differences observed between the training and testing cohorts according to the balance test (Supplementary Table 1). The AUC values of the training and testing cohorts for three different follow-up duration are presented in supplementary Fig. 1, 2. Most of the 10-year AUC values in train and test cohort were found to be high. All model assessment results confirmed that our Cox models fit well.

Association of osteoporosis risk and mortality

The brief systematic review indicated that the OSTA may serve as a reliable and valid screening tool for assessing osteoporosis risk among Asians of both genders. Regardless of the cut-off values for OSTA (≤-1, 0, or -4) and BMD T-score (≤-2.5), the comparison with BMD measured by DXA demonstrated that the results of OSTA values were robust, exhibiting high sensitivity and specificity, along with a substantial AUC. Detailed information is provided in Supplementary Table 2.

The relationship between osteoporosis risk and the risk of all-cause and cause-specific mortality was examined using Cox proportional regression models adjusted for covariates (Table 2). Participants with high osteoporosis risk exhibited a significantly higher risk of all-cause mortality (HR = 2.54, 95%CI = 2.11–3.06), heart disease mortality (HR = 1.57, 95%CI = 1.09–2.26), CVD mortality (HR = 1.52, 95%CI = 1.05–2.19), respiratory disease mortality (HR = 2.29, 95%CI = 1.44–3.63), cancer mortality (HR = 1.19, 95%CI = 1.03–1.79) and other cause mortality (HR = 3.48, 95%CI = 2.60–4.67) compared to the low-risk group. Among the elderly male population, similar associations were observed; however, among elderly females only an increased risk of all-cause mortality was significantly associated with high osteoporosis risk. (Supplementary Tables 3–4).

A non-linear relationship between OSTA value and the risk of all-cause and cause-specific mortality by sex is illustrated in Figs. 2 and 3. Both male and female

Table 1 Baseline characteristics stratified by osteoporosis risk in Chinese elderly population, CLHLS 2002–2018

		Total	Osteoporosis risk			*P*-value [a]
			Low	Middle	High	
Number		12,711	251	929	11,531	
Age (years)		82.7(82.6–82.9)	71.6(71.0–72.1)	73.0(72.8–73.3)	85.8(85.7–86.0)	<0.001
Weight (kilogram)		50.2(50.0–50.4)	65.3(63.7–67.0)	59.0(58.5–59.5)	49.2(49.0–49.4)	<0.001
SBP (mmHg)		138.5(137.4–139.6)	136.9(134.4–139.4)	135.0(132.2–137.9)	138.8(137.7–140.0)	0.189
DBP(mmHg)		90.4(89.2–91.6)	86.3(84.8–87.7)	86.9(84.1–89.8)	90.8(89.5–92.1)	0.161
OSTA		−10.9(−11.1–10.8)	13.8(10.9–16.6)	−2.81(−2.86–2.76)	−12.1(−12.2–12.0)	<0.001
Gender	Male	6115	185(3.0%)	617(10.1%)	5313(86.8%)	<0.001
	Female	6596	66(1.0%)	312(4.7%)	6218(94.3%)	
Category of residence	Urban	3052	93(3.0%)	234(7.7%)	2725(89.3%)	<0.001
	Rural	9659	158(1.6%)	695(7.2%)	8806(91.2%)	
Self-reported quality of life	Good	7169	167(2.3%)	575(8.0%)	6427(89.6%)	<0.001
	So-so/bad	5542	84(1.5%)	354(6.4%)	5104(92.1%)	
Smoke at present	Yes	2671	84(3.1%)	290(10.8%)	2297(86.0%)	<0.001
	No	10,040	167(1.7%)	639(6.4%)	9234(91.9%)	
Drink at present	Yes	2718	80(2.9%)	283(10.4%)	2355(86.6%)	<0.001
	No	9993	171(1.7%)	646(6.5%)	9176(91.8%)	
Exercise at present	Yes	4497	127(2.8%)	436(9.7%)	3934(87.5%)	<0.001
	No	8214	124(1.5%)	493(6.0%)	7597(92.5%)	
Educational level	Low	11,926	220(1.8%)	845(7.1%)	10,861(91.1%)	<0.001
	High	785	31(3.9%)	84(10.7%)	670(85.4%)	
Financial condition	Good	10,282	226(2.1%)	792(7.7%)	9264(90.1%)	<0.001
	Bad	2429	25(1.0%)	137(5.6%)	2267(93.3%)	
Current marital status	Couple	4632	181(3.9%)	659(14.2%)	3792(81.8%)	<0.001
	Single	8079	70(0.8%)	270(3.3%)	7739(95.7%)	
Adequate medical service	Yes	11,411	245(2.1%)	882(7.7%)	10,284(90.1%)	<0.001
	No	1300	6(0.4%)	47(3.6%)	1247(95.9%)	
Dietary habits (almost everyday, %)						
	Fresh fruits	10.9	18.7	11.1	10.7	<0.001
	Vegetables	54.1	61.8	60.9	53.3	<0.001
	Meat	38.9	43.8	40.2	38.7	0.276
	Fish	23.2	31.1	25.9	22.8	<0.001
	Eggs	43.2	53.8	47.9	42.6	<0.001
	Sugar	27.8	24.3	24.4	28.2	0.014
	Tea	31.8	40.2	38.8	31.1	<0.001
History of diseases diagnosed by hospital (Yes, %)						
Diabetes		13.2	14.7	12.8	13.2	0.911
Heart disease		18.9	22.7	18.3	18.9	0.490
Respiratory disease		19.3	18.3	18.7	19.4	0.873
Cardiovascular disease		14.6	15.9	15.5	14.5	0.787
Cancer		9.1	8.8	8.8	9.2	0.910

Abbreviation: CLHLS, Chinese Longitudinal Healthy Longevity Survey; SBP, systolic blood pressure; DBP, diastolic blood pressure; OSTA, Osteoporosis Self-Assessment Tool for Asians; CI, confidence interval. Continuous variables were presented as mean and its 95%CI. Categorical variables were presented as number of cases and its proportion. [a] One-way ANOVA analyses were employed for comparing differences in continuous variables. Chi-square tests were used for categorical variables

participants exhibited a statistically significant L-shaped association between osteoporosis risk and both all-cause mortality and cause-specific mortality. However, this significant association diminished as OSTA values increased in certain groups.

Subgroup and sensitive analyses

The association between osteoporosis risk and all-cause and cause-specific mortality, stratified by all potential risk factors, is depicted in Fig. 4. Subgroup analyses did not reveal any substantial changes in the association between osteoporosis risk and cause-specific mortality. Across all subgroups, the relationship between osteoporosis risk and both all-cause and other cause mortality remained statistically significant. Overall, these analyses confirm that individuals with higher osteoporosis risk have a greater likelihood of experiencing all-cause mortality compared to those with lower osteoporosis risk.

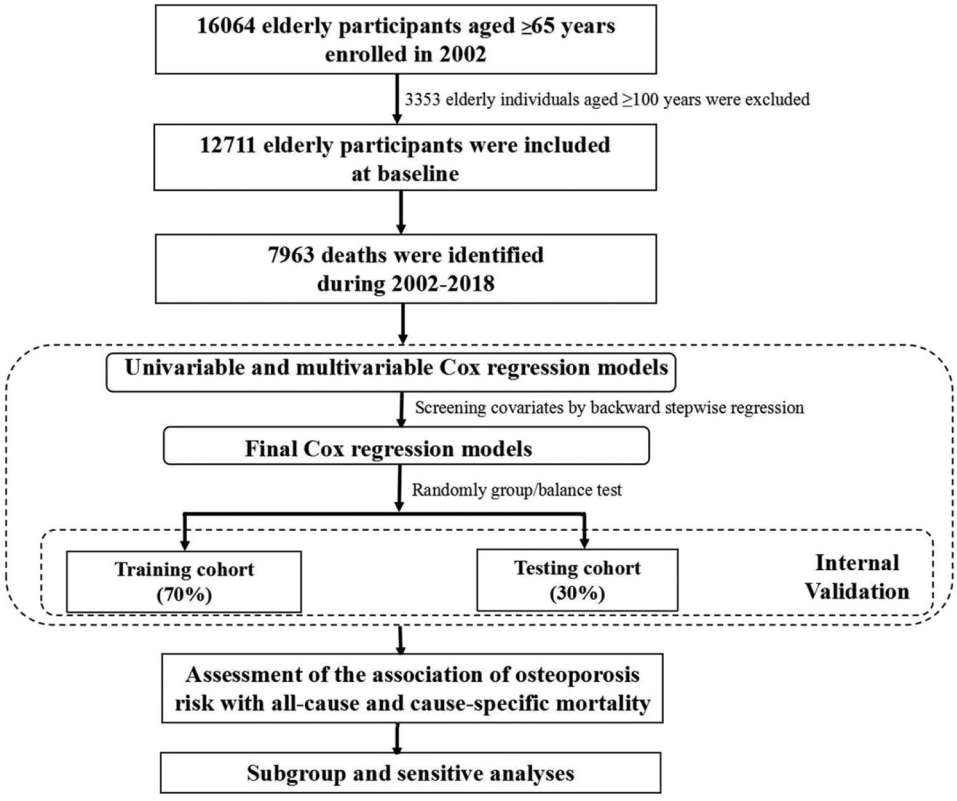

Fig. 1 Flow chart illustrating the research process for the present study

The results of sensitivity analyses, as presented in supplementary Table 5, demonstrated consistent notable outcomes when re-evaluating the findings using a subset of participants.

Discussion

Our findings suggest a significant association between a high risk of osteoporosis and increased risks of both all-cause mortality and cause-specific mortality among the elderly population. Furthermore, we observed an L-shaped relationship between OSTA increment and mortality in participants of both genders. The predictive value of OSTA levels for mortality in the elderly population was consistently strong throughout this study.

In this study, we found a significant association between a higher risk of all-cause mortality and an elevated osteoporosis risk among total participants. Previous studies have also reported similar findings, however, they defined osteoporosis based on BMD. An earlier meta-analysis revealed a significant association between lower total hip/femoral neck BMD and increased all-cause mortality risk [38]. Famous study CAIFOS (Calcium Intake Fracture Outcome study) suggested that the diagnosis of osteoporosis through broadband ultrasound attenuation was linked to a 1.15-fold increase in the risk of all-cause mortality [10]. The findings of a series of studies conducted on elderly individuals in the United States as part of the National Health and Nutrition Examination Survey (NHANES) revealed a significant association between low BMD and an increased risk of all-cause mortality [11, 13, 14]. Additionally, the maintenance of BMD levels after a hip fracture remained beneficial in reducing the risk of all-cause mortality and preventing osteoporosis [39]. Conversely, previous studies have not yet reached a definitive conclusion regarding the association between osteoporosis/BMD and cause-specific mortality. In this study, a significant association between elevated risk of osteoporosis and cause-specific mortality was observed exclusively among male participants. The Rotterdam Study suggested an inverse correlation between BMD and mortality from chronic lung disease in all participants, while no significant association was observed with CVD mortality [9]. In contrast, Domiciano et al. demonstrated a significant association between low BMD and CVD mortality in community-dwelling older adults [7]. The subsequent investigation conducted by CAIFOS yielded a similar finding, further indicating that osteoporosis is independently associated with CVD mortality in elderly women, irrespective of BMD and established CVD risk factors [10]. Two meta-analyses have also provided support for the association between low BMD and an increased risk of CVD-related mortality [38, 40]. The NHANES provided a valuable opportunity to investigate the association between osteoporosis and

Table 2 Association of osteoporosis risk and all-cause and cause-specific mortality among total elderly population in 2002–2018 CLHLS

Cause of mortality	Osteoporosis risk	HR (univariable)	HR (multivariable)	HR (final) [a]
All-cause mortality				
	Low	Ref.	Ref.	Ref.
	Middle	0.79 (0.64–0.97)	0.74 (0.60–1.21)	0.74 (0.60–1.21)
	High	**3.27 (2.72–3.93)**	**2.54 (2.11–3.05)**	**2.54 (2.11–3.06)**
	P-value	<0.001	<0.001	<0.001
Heart disease mortality				
	Low	Ref.	Ref.	Ref.
	Middle	0.66 (0.44–1.00)	0.69 (0.45–1.04)	0.69 (0.46–1.04)
	High	**1.58 (1.10–2.27)**	**1.55 (1.07–2.24)**	**1.57 (1.09–2.26)**
	P-value	<0.001	<0.001	<0.001
Cardiovascular disease mortality				
	Low	Ref.	Ref.	Ref.
	Middle	0.80 (0.53–1.20)	0.77 (0.51–1.16)	0.77 (0.51–1.17)
	High	**1.68 (1.17–2.42)**	**1.49 (1.03–2.16)**	**1.52 (1.05–2.19)**
	P-value	<0.001	<0.001	<0.001
Respiratory disease mortality				
	Low	Ref.	Ref.	Ref.
	Middle	0.97 (0.58–1.60)	0.90 (0.55–1.50)	0.92 (0.55–1.52)
	High	**2.69 (1.71–4.25)**	**2.23 (1.41–3.53)**	**2.29 (1.44–3.63)**
	P-value	<0.001	<0.001	<0.001
Cancer mortality				
	Low	Ref.	Ref.	Ref.
	Middle	0.67 (0.42–1.06)	0.65 (0.40–1.05)	0.65 (0.40–1.05)
	High	**1.26 (1.04–1.89)**	**1.18 (1.01–1.77)**	**1.19 (1.03–1.79)**
	P-value	<0.001	<0.001	<0.001
Other causes mortality				
	Low	Ref.	Ref.	Ref.
	Middle	0.77 (0.55–1.07)	0.69 (0.49–1.06)	0.69 (0.49–1.06)
	High	**5.08 (3.80–6.80)**	**3.49 (2.60–4.67)**	**3.48 (2.60–4.67)**
	P-value	<0.001	<0.001	<0.001

Abbreviation: CLHLS, Chinese Longitudinal Healthy Longevity Survey; HR, hazard ratio; CI, confidence interval; Ref., reference. [a] The backward stepwise regression method was employed to screen for statistically significant covariates in both univariable and multivariable models, which were included in the final models for analysis

the risk of mortality related to specific causes. According to the findings from the Third NHANES, there was no significant association observed between low BMD and the risk of coronary heart disease death or stroke-related mortality among all participants [17]. Looker et al. revealed a significant inverse correlation between BMD and mortality associated with chronic obstructive pulmonary disease (COPD), based on the analysis of data from the Third NHANES as well [15]. A 6.8-year median follow-up study by NHANES demonstrated that a significant association between higher BMD levels and reduced mortality risks for cancer and heart diseases, with variations observed across genders [14]. Nevertheless, recent research has failed to establish a correlation between BMD and cancer mortality [11]. Besides the NHANES, we also observed a non-significant correlation between BMD and breast cancer-specific mortality among older individuals in Australia during a median follow-up period of 20.7 years [18]. Notably, the study conducted by Campos-Obando revealed a significant correlation between BMD and cancer mortality in males [9]. Meanwhile, similar findings have been observed not only in Western populations but also among Asian populations. The Dong-gu study indicated a U-shaped association between BMD and all-cause, cancer-related, and other-cause mortality; however, this association was not found with CVD mortality in male participants [41]. Suzuki et al. suggested that increasing and maintaining high BMD at the femoral neck in elderly Japanese women may not only help prevent hip fractures but also potentially reduce the risk of mortality [61]. Among elderly Chinese individuals, hip BMD-particularly trochanteric BMD-has been identified as an independent risk factor for postoperative mortality following osteoporotic hip fractures [62].

Previous projections from the 1990s estimated that by the year 2050, there would be between 4.5 and 6.2 million

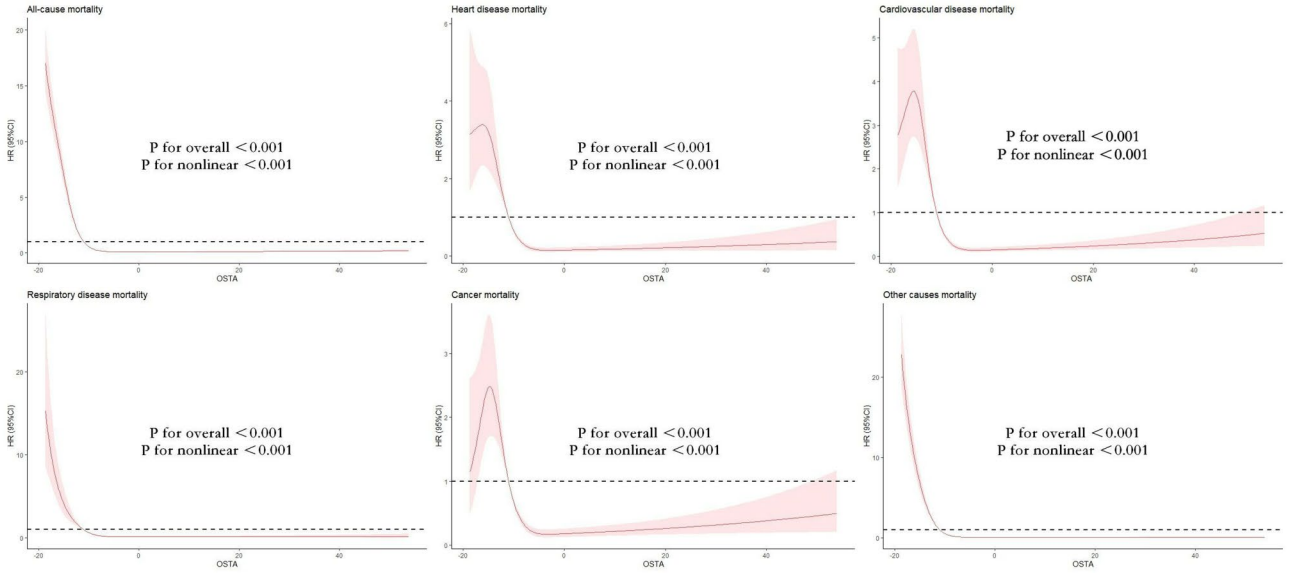

Fig. 2 Nonlinear association between OSTA and risk of all-cause, heart disease, CVD, respiratory disease, cancer and other cause mortality among male participants. Associations were assessed using multivariable Cox regression models with restricted cubic splines

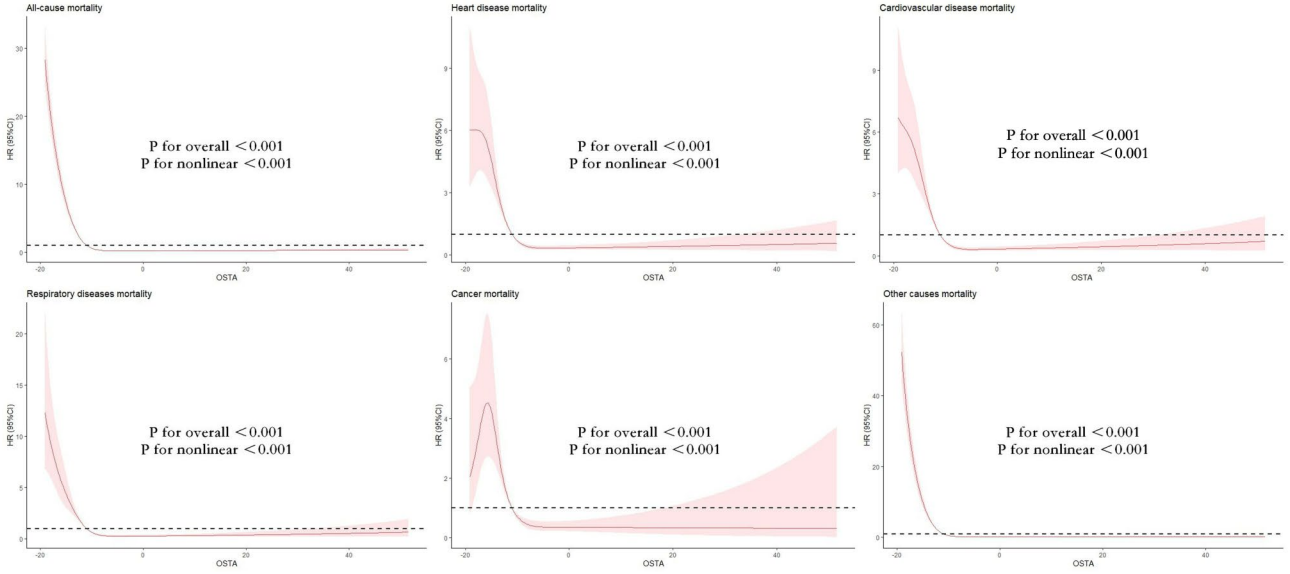

Fig. 3 Nonlinear association between OSTA with risk of all-cause, heart disease, CVD, respiratory disease, cancer and other cause mortality among female participants. Associations were assessed using multivariable Cox regression models with restricted cubic splines

elderly patients worldwide suffering from hip fractures related to osteoporosis, with approximately half of these cases originating from Asia [6]. Former studies have suggested a strong association between BMD and ethnicity; specifically, it has been observed that Black individuals tend to have higher BMD compared to Caucasians. Hispanics exhibit BMD levels similar to those of Caucasians, while Asians generally present with the lowest BMD [19]. Moreover, the Asian dietary pattern, characterized by a greater inclination towards vegetarianism and lower meat consumption compared to Western diets, may offer valuable insights into the high prevalence of osteoporosis. This dietary pattern is associated with reduced protein intake, which can lead to decreased calcium-related vitamin D absorption and subsequently result in lower BMD and an increased risk of fractures [63–64]. Furthermore, existing evidence indicates that vitamin D deficiency is prevalent in regions such as the Middle East, India, China, and Japan, while it is less common in Northern Europe [65]. On another note, phytates present in the Asian diet may negatively affect calcium absorption. Shatrugana et al. reported that the estimated

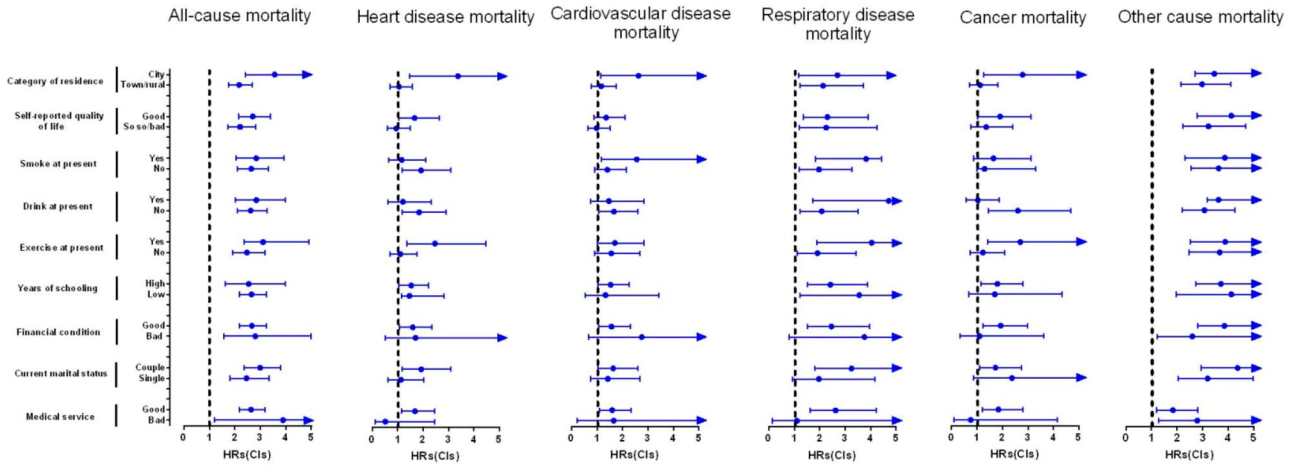

Fig. 4 Association between OSTA with all-cause heart disease, CVD, respiratory disease, cancer and other cause mortality stratified by different factors. Graph shows the hazard ratios (HRs) and 95% CIs for all-cause mortality as well as cause-specific mortality

dietary intake of calcium among their study participants was only 270 ± 57 mg/day [66]. Although BMD testing is widely acknowledged as the gold standard for diagnosing osteoporosis, it frequently faces challenges due to the substantial population in need of testing and delays in implementing preventive measures against this condition. For instance, the limited accessibility of DXA presents significant challenges, particularly considering that there are fewer than one DXA machine per million residents in many Asian countries [19]. The OSTA has the potential to address these issues to a certain degree, owing to its comprehensive and self-testing risk assessment tool specifically tailored for the Asian population [20]. The cost-effectiveness analysis revealed that, compared to no screening, OSTA contributed an increase of between 0.00035 and 0.00125 QALYs for males and between 0.00164 and 0.00443 QALYs for females, with the most significant increases observed at age 75 for both genders [67].

The utilization of linear and nonlinear analyses offered a comprehensive perspective on the trajectory of the relationship between exposure factors and health outcomes. The findings of several prior studies have indicated a significant inverse linear relationship between BMD and mortality, but fewer studies have explored the potential nonlinear associations. The Rotterdam Study reported a nonlinear relationship between BMD and mortality in men independently comorbidity, whereas no significant relationship was observed in women [16]. The NHANES demonstrated a statistically significantly L-shaped association for all-cause mortality with BMD increment. a statistically significant L-shaped association between BMD increment and all-cause mortality. However, the relationship between higher BMD levels and decreased risk of cancer and heart disease mortality was more pronounced in male and female participants, respectively [14].

To the best of our knowledge, this might be the first study to demonstrate the relationships between osteoporosis risk/OSTA with all-cause and cause-specific mortality among elderly general population. The second point is that present study addressed the gap in understanding the relationship between osteoporosis risk and mortality among Asian populations by utilizing a nationally representative, large-scale sample with long-term follow-up. Finally, a significant proportion of elderly individuals with osteoporosis are commonly diagnosed following fragility fractures, however, these fractures have been associated with elevated mortality rates in the elderly population. Asian countries, particularly China, are experiencing a demographic shift towards an aging population. The prevalence of high osteoporosis risk among the elderly population is expected to increase significantly in a short period of time. In combination, early screening of high-risk populations, primary prevention, and timely intervention are crucially essential in mitigating the significant risk of fractures, increased mortality rates, and escalating healthcare costs among the elderly population.

The study also necessitates acknowledgment of several inherent limitations. Firstly, the questionnaires collected some valuables that may be susceptible to self-reported bias. Secondly, although we incorporated numerous covariates associated with mortality in our analyses, there might still exist uncontrolled and unmeasured confounders on the causal chain. Then, results of sensitive analyses remained largely unchanged even after excluding participants with a history of diseases, despite the possibility that one participant may have multiple instances of disease history. Additionally, while our brief systematic review suggested that OSTA could serve as a reliable, cost-effective, non-invasive screening tool for assessing osteoporosis risk among Asian populations when compared to BMD measured by DXA, the CLHLS project did

not collect BMD values. This limitation hinders our ability to assess the reliability and validity of the osteoporosis risk assessment tool presented in this study. Finally, given the relatively high mean age of participants in our study, it is important to consider that individuals without osteoporosis risk might still face an increased risk of mortality solely due to advanced age. Therefore, caution should be exercised when comparing our findings with those from other studies.

In conclusion, our study findings suggest that a high risk of osteoporosis is independently associated with an increased risk of mortality. There was a significantly pronounced L-shaped association between OSTA levels and mortality. OSTA may offer a promising avenue for screening the osteoporosis risk in elderly Asian individuals, not only for preventing osteoporosis and related fractures but also potentially reducing the risk of mortality.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12877-025-05843-7.

Supplementary Material 1: The AUC values of the training cohorts for three distinct follow-up duration

Supplementary Material 2: The AUC values of the testing cohorts for three distinct follow-up duration

Supplementary Material 3: Supplementary Table 1. Balance test between training cohort and testing cohort using the 2002-2018 CLHLS. **Supplementary Table 2.** Performance of OSTA in identifying osteoporosis compared to BMD measured by DXA [21–23, 29, 45–60]. **Supplementary Table 3.** Association of osteoporosis risk and all-cause and cause-specific mortality among male elderly population in 2002-2018 CLHLS. **Supplementary Table 4.** Association of osteoporosis risk and all-cause and cause-specific mortality among female elderly population in 2002-2018 CLHLS. **Supplementary Table 5.** Sensitive analyses of osteoporosis risk and all-cause and cause-specific mortality in two random cohorts using the 2002-2018 CLHLS

Acknowledgements

Thanks for the data derived from the Chinese Longitudinal Healthy Longevity Survey (CLHLS), which was supported by United States Department of Health and Human Services. National Institutes of Health, National Institute on Aging (R01AG023627), National Natural Science Foundation of China (71233001), National Basic Research Program of China (2013CB530700).

Author contributions

Yan-Yu Liu contributed to the study concept. Xing-Bing Pan had full access to all the data in the study and take responsibility for the integrity of the data. Qing-Ya Ma and Teng Gao contributed to the statistical analysis and tables' development of this article. Xing-Bing Pan, Tai Zhang, Jian Xun and Xiang-Tao Ma interpreted the findings and drafted the article. All the authors contributed to the critical revision of the article for important intellectual content.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability

Data available on request from authors.

Declarations

Ethical approval

The CLHLS study received ethical approval from the Institutional Review Board (IRB) of Peking University (IRB00001052-13074).

Consent to participate/publication

Not applicable.

Competing interests

The authors declare no competing interests.

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Received: 5 July 2024 / Accepted: 6 March 2025
Published online: 26 March 2025

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