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A Study on the Prevalence of Osteoporosis in People with Different Altitudes in Sichuan, China

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Purpose: Osteoporosis is a major health concern among the elderly, underscoring the importance of investigating its prevalence across different geographical regions. There is a current research gap regarding the incidence of osteoporosis and its variation by altitude within Sichuan, China. This study aimed to assess the prevalence of osteoporosis among populations residing at different altitudes in western Sichuan Province.

Basic Procedures: This study utilized data from a population-based cohort in Sichuan, China. Representative locations were selected, and cluster random sampling was employed to conduct cohort studies across multiple sites in southwestern China. T Baseline data were collected from populations in Mianzhu, Kangting, and Sertar between July 2020 and August 2021. To assess differences in osteoporosis incidence among populations at different altitudes and with varying characteristics, we applied Chi-square and rank-sum tests.

Main Findings: The study involved 4074 participants, including 1404 males (34.46%) and 791 individuals diagnosed with osteoporosis (19.42%). The prevalence of osteopenia in mid-altitude and high-altitude regions was 20.05% and 16.28%, respectively, while the prevalence of osteoporosis was significantly different, at 25.85% in mid-altitude areas compared to 13.00% in high-altitude areas ($P < 0.001$). Further analysis identified statistically significant differences in the prevalence of osteopenia and osteoporosis among females ($P<0.001$), middle-aged ($P=0.015$) and elderly populations ($P=0.038$), as well as among individuals who were underweight ($P=0.011$), normal weight ($P<0.001$), overweight ($P<0.001$), and obese ($P=0.038$). As altitude increased, the prevalence of osteoporosis decreased in all groups except the elderly, while the prevalence of osteopenia decreased among women and across various BMI categories, but increased among middle-aged and elderly individuals. Additionally, in high-altitude regions, Kangting recorded an 18.10% prevalence of osteopenia and a 14.26% prevalence of osteoporosis, compared to Sertar, which exhibited a 6.54% prevalence of osteopenia and a 6.23% prevalence of osteoporosis, indicating significant differences ($P<0.001$).

Conclusion: This study demonstrates that higher altitudes are associated with a decreased prevalence of osteopenia and osteoporosis, particularly among females and middle-aged individuals. These results emphasize the importance of developing region-specific osteoporosis prevention strategies.

Keywords: osteoporosis, aging, prevalence, altitude, Sichuan province

Introduction

Osteoporosis, characterized by reduced bone density and weakened bone structure, imposes significant social and economic burdens, primarily due to fractures.[1] Globally, it is alarming that every three seconds, an individual suffers an osteoporotic

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fracture, with approximately half of all women and one in five men over 50 experiencing at least one such fracture in their lifetime.[2] Furthermore, individuals who sustain an initial osteoporotic fracture have a 50% chance of suffering subsequent fractures.[2] Between 20% and 24% of patients with hip fractures die within one year of the injury, and survivors often face prolonged recovery periods, characterized by chronic pain, depression, and a significant decline in quality of life.[3–5] In 2019, the total direct cost of osteoporotic fractures in the European Union was €56.9 billion. When calculated as twice the per capita GDP, the cost of lost Quality Adjusted Life Years (QALYs) in 2019 amounted to €112.9 billion.[6] Nevertheless, early intervention and treatment of osteoporotic fractures can significantly reduce the likelihood of future fractures.[7–9] Thus, gaining insights into osteoporosis prevalence and characteristics within a specific region is crucial. It paves the way for increased awareness among the general public, healthcare providers, and policymakers, fostering early screening, diagnosis, and effective management.

In China, the swift aging of its population has turned osteoporotic fractures into a major health issue. Recent nationwide surveys revealed that 32.1% of postmenopausal women and 6.9% of men over 50 are affected by osteoporosis.[10] Future forecasts paint a concerning picture, estimating that by 2035, osteoporotic fractures in critical regions such as the wrist, spine, and hip could total nearly 4.83 million cases, with this figure projected to rise to around 5.99 million by 2050.[11] Yet, given China's extensive and varied terrain, encompassing everything from plateaus and mountains to hills, plains, and deserts, accurately pinpointing remains a significant challenge. This complexity is further compounded by the fact that existing studies have sampled only 20,416 individuals, limiting the ability to draw broad conclusions about the nationwide prevalence of osteoporosis.[11]

Sichuan Province, located in southwestern China, is known for its diverse landscape. According to the Sichuan Province Yearbook, the province exhibits significant east-west geographical diversity with a complex and varied terrain characterized by marked elevation differences, with the west being distinctly higher than the east. The western part comprises plateaus and mountains, with elevations mostly above 4000 meters, while the eastern part consists of basins and hills, generally ranging from 1000 to 3000 meters in elevation. Notably, the central basin's purple hill zone ranges between 400 to 800 meters in elevation.[12] These diverse altitudinal regions experience significant environmental differences; for instance, the basin areas enjoy a warm and humid climate with mild winters and hot summers, whereas the high-altitude areas in the northwest feature a cold climate with alpine meadow vegetation. This results in lower average temperatures, reduced oxygen levels, and increased sunlight exposure at higher altitudes compared to lower regions.[12] Previous studies have shown inconsistent effects of these factors on bone metabolism, and even contradictory impacts. For example, oxygen concentration is a key factor influencing bone metabolism, with hypoxia being a significant cause of osteoporosis in high-altitude areas.[13] Conversely, adequate sunlight satisfies most people's vitamin D requirements, with vitamin D deficiency being a major cause of osteoporosis.[14] Research has also found that animals raised in warmer climates develop longer limbs compared to those in colder environments.[15] Due to these complexities, the prevalence of osteoporosis across different altitudes in Sichuan remains unclear. Nevertheless, understanding these prevalence patterns is essential for informing regional strategies for osteoporosis prevention and management. Therefore, leveraging baseline data from a natural, population-based cohort study, this study aimed to examine the prevalence of osteoporosis among populations residing at different altitudes in western Sichuan Province, as well as to analyze how the prevalence varies among different demographic groups with changes in altitude.

Materials and Methods

Participants

Data Source

Participants were recruited from the Health Project at West China Hospital, Sichuan University, located in Sichuan Province. This cohort study, based on a natural population within Sichuan Province, strategically selected representative locales using a cluster random sampling technique. The research spanned various regions of southwestern China, capturing data from communities diverse in geography, economy, culture, and ethnicity. Initiated in July 2019, the study has since completed its collection of baseline data. Participants from three specific areas in Sichuan Province—Mianzhu, Kangting, and Sertar—were selected for baseline analysis. This study complies with the Declaration of Helsinki, and the Ethics Committee of West China Hospital, Sichuan University, granted ethical approval (Approval No. 2019(145)). Every participant provided informed

consent, as evidenced by their signed consent forms. The inclusion criteria were: 1) being 20 years or older, 2) holding a local household registration, and 3) for non-locals, having resided in the area for a minimum of six months with no intention to move within the next five years. The exclusion criterion was the absence of bone density measurement data. This study was registered with the China Clinical Trials Registry (Registration No. ChiCTR1900024623).

Measurements

Data collected included basic demographic information, body measurements, and bone mineral density (BMD) assessments. The collection of basic information recorded each participant's name, sex, age, and a unique ID number for identification. Body measurements included height and weight, from which body mass index (BMI) was calculated. BMD was measured using a dual-energy X-ray absorptiometry (DXA) scanner, specifically the Magic DXA6100 model from Chongqing Maijike Medical Technology Co., Ltd. This device, which meets the product technical requirements (Number: Yuxiezhun 20192060239) and holds a production license (Number: Yushiyaoshenxi 20190028), measures areal bone density, expressed in g/cm². For these measurements, the distal third of the radius on the nondominant forearm was selected as the scanning site.[16]

Outcome Definitions

1. Age Classification: Following the World Health Organization's age classification criteria, our study categorized participants into three groups: young individuals (under 44 years old), middle-aged individuals (45 to 59 years old), and elderly individuals (60 years and older).[17]
2. BMI: According to the Long-Term Weight Management and Pharmacological Clinical Application Guidelines for Obese Patients (2024 Edition), participants were classified based on their BMI into underweight (BMI < 18.5 kg/m²), normal weight (BMI 18.5–23.9 kg/m²), overweight (BMI 24–27.9 kg/m²), and obese (BMI ≥ 28 kg/m²).[18]
3. Altitude Classification: In accordance with the standards set by the International Organization for Standardization (ISO)[19] and the International Civil Aviation Organization (ICAO),[20] the study locations in Sichuan were classified based on altitude. Mianzhu has an average altitude of 588 meters and is primarily hilly, categorized as mid-altitude. Kangting, positioned on the southeastern edge of the Qinghai–Tibet Plateau, has an average altitude between 2500 and 3000 meters, and is thus considered high altitude. Sertar, with an average altitude of 4127 meters and predominantly plateau and hilly terrain, is also classified as high altitude (refer to Figure 1).
4. Osteoporosis Diagnosis: In line with the World Health Organization's guidelines, participants were categorized into three groups based on their T-scores and Z-scores. For postmenopausal women and men aged 50 years and above, a T-score was used to diagnose bone health status: normal bone density was defined as a T-score of −1.0 or higher, osteopenia was identified with a T-score between −1.0 and −2.5, and osteoporosis was diagnosed when the T-score was −2.5 or lower. For children, premenopausal women, and men under 50, osteopenia was diagnosed using a Z-score of −2.5 or lower.[21,22] Unfortunately, this study did not capture the specific ages at menopause for female participants. Consequently, the study applied the average menopause age for Chinese women, documented as 49 years, to guide the analysis.[23]

Statistical Analysis

This study utilized percentages to describe categorical variables. The R×C chi-square test was applied to assess statistical significance across participant characteristics. When more than 20% of the cells in the RxC table had expected counts less than 5, or if any cell had an expected count less than 1, the rank-sum test was applied. A *P*-value of less than 0.05 was considered statistically significant, with *P*-values less than 0.001 reported as $P < 0.001$. All statistical analyses were performed using SPSS software, version 29.0.

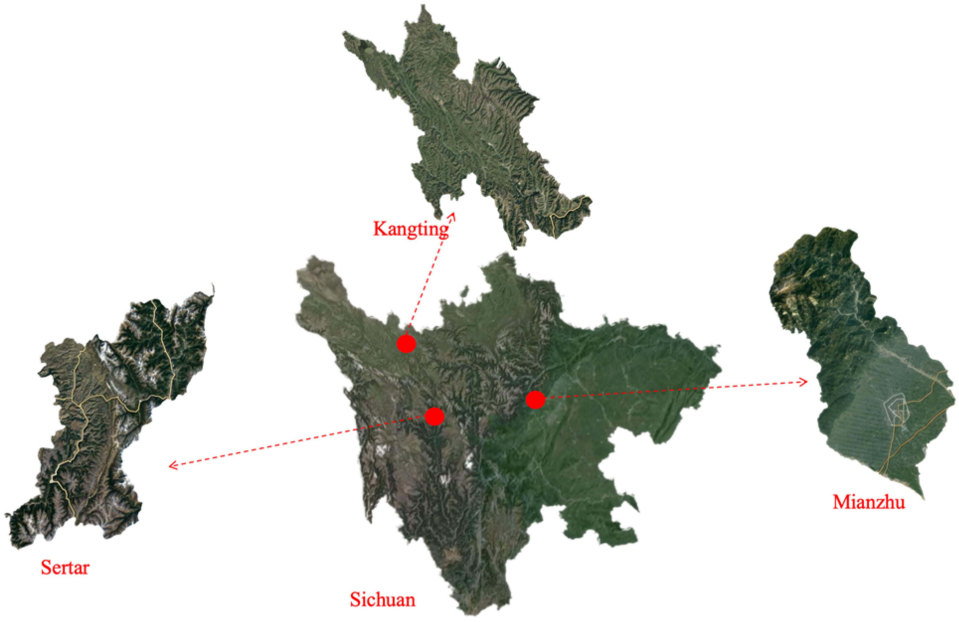

Figure 1 Source of participants.

Results

The study included a cohort of 4074 participants, with 1404 males (34.46%) and 2670 females (65.54%), with average BMD values of 0.491±0.091 g/m² and 0.367±0.085 g/m², respectively. A significant portion of the cohort, 1854 individuals (45.51%), were elderly, with an average BMD of 0.378±0.105 g/m². The majority of participants were classified as normal weight (43.40%), followed by overweight individuals (38.24%), with respective BMD values of 0.410±0.104 g/m² and 0.408±0.106 g/m², respectively. The cohort was almost evenly split in terms of altitude residence, with 2035 participants (49.95%) residing in mid-altitude areas (Mianzhu) and showing an average BMD of 0.399±0.111 g/m², while 2039 participants (50.05%) lived in high-altitude regions, where the average BMD was 0.421±0.098 g/m². This high-altitude group included 1718 participants from Kangting and 321 from Sertar. Across the entire cohort, 791 individuals (19.42%) were diagnosed with osteoporosis and 740 (18.16%) with osteopenia, having average BMDs of 0.276±0.011 g/m² and 0.330±0.030 g/m², respectively. For a detailed breakdown, please refer to Table 1.

Within the same altitude zones, significant differences in osteoporosis incidence were observed across gender and age groups ($P < 0.001$). In the mid-altitude region, osteopenia affected 24.67% of females compared to 10.78% of males, while osteoporosis was present in 36.82% of females and 3.84% of males. As age increased, the prevalence of both osteopenia and osteoporosis also rose; younger individuals generally had normal bone density, while the prevalence of osteopenia increased from 17.24% to 22.10%, and osteoporosis from 11.59% to 33.91% as individuals transitioned from middle to old age. In high-altitude areas, osteopenia was observed in 19.21% of females and 11.00% of males, while osteoporosis affected 18.14% of females versus 3.71% of males. As in mid-altitude areas, the prevalence of both osteopenia and osteoporosis increased with age in high-altitude regions, with osteopenia rising from 2.17% in younger individuals to 25.89% among the elderly, and osteoporosis reaching 36.40% among the elderly population. In mid-altitude regions, no statistically significant differences in osteoporosis prevalence were observed across different BMI categories ($P = 0.719$). However, in high-altitude regions, osteoporosis prevalence increased with rising BMI, while the prevalence of osteopenia remained stable, and these differences were statistically significant ($P = 0.008$). Among participants with a BMI < 18.5 kg/m², the prevalence of normal bone density, osteopenia, and osteoporosis were 82.00%, 12.00%, and 6.00%, respectively. For those with a BMI ≥ 28.0 kg/m², the respective prevalences were 66.36%, 16.36%, and 17.29%. For further details, refer to Table 2.

In the mid-altitude region, the prevalence of osteopenia and osteoporosis were 20.05% and 25.85%, respectively. Conversely, in the high-altitude region, these rates were 16.28% for osteopenia and 13.00% for osteoporosis, with the differences being statistically significant ($P < 0.001$). Further analysis revealed significant differences in the prevalence

Table 1 Basic Characteristics

	Number	Percentage	BMD (mean, g/m^2)	Standard Deviation(g/m^2)
Total	4074	100.00%	0.410	0.105
Sex				
Male	1404	34.46%	0.491	0.091
Famel	2670	65.54%	0.367	0.085
Age (Year)				
≤44	596	14.63%	0.470	0.080
45–59	1626	39.91%	0.424	0.095
≥60	1854	45.51%	0.378	0.105
BMI(Kg/m^2)				
<18.5	112	2.75%	0.423	0.107
18.5-23.9	1768	43.40%	0.410	0.104
24–27.9	1558	38.24%	0.408	0.106
≥28.0	636	15.61%	0.412	0.107
Diagnosis				
Normal bone density	2543	62.42%	0.475	0.076
Osteopenia	740	18.16%	0.330	0.030
Osteoporosis	791	19.42%	0.276	0.011
Region				
Low altitude-Mianzhu	2035	49.95%	0.399	0.111
High altitude	2039	50.05%	0.421	0.098
High altitude-Kangting	1718	42.17%	0.411	0.095
High altitude-Sertar	321	7.88%	0.472	0.097

Table 2 Differences in Osteoporosis Among Population Subgroups with Similar Altitudes

	Mid Altitude(N(%))				High Altitude(N(%))			
	Normal bone density	Osteopenia	Osteoporosis	*P**	Normal bone density	Osteopenia	Osteoporosis	*P**
Sex				<0.001				<0.001
Male	578(85.38%)	73(10.78%)	26(3.84%)		620(85.28%)	80(11.00%)	27(3.71%)	
Female	523(38.51%)	335(24.67%)	500(36.82%)		822(62.65%)	252(19.21%)	238(18.14%)	
Age(Year)				<0.001				<0.001
≤44	41(100.00%)	0(0%)	0(0%)		541(97.83%)	12(2.17%)	0(0%)	
45–59	479(71.17%)	116(17.24%)	78(11.59%)		700(73.45%)	182(19.10%)	71(7.45%)	
≥60	581(43.98%)	292(22.10%)	448(33.91%)		201(37.71%)	138(25.89%)	194(36.40%)	
BMI(Kg/m^2)				0.719				0.008
<18.5	36(58.06%)	10(16.13%)	16(25.81%)		41(82.00%)	6(12.00%)	3(6.00%)	
18.5-23.9	562(55.04%)	204(19.98%)	255(24.98%)		549(73.49%)	106(14.19%)	92(12.32%)	
24–27.9	385(51.75%)	156(20.97%)	203(27.28%)		568(69.78%)	150(18.43%)	96(11.79%)	
≥28.0	118(56.73%)	38(18.27%)	52(25.00%)		284(66.36%)	70(16.36%)	74(17.29%)	

Notes: Statistical analysis was performed using the R×C chi-square test. If more than 20% of the cells in the R×C table had expected counts less than 5, or if any cell had an expected count less than 1, the rank-sum test was applied. *For *P*-values less than 0.001, results are reported as *P*<0.001.

of normal bone density, osteopenia, and osteoporosis across altitudes among females ($P < 0.001$), middle-aged individuals ($P = 0.015$), the elderly ($P = 0.038$), and individuals classified as underweight ($P = 0.011$), of normal weight ($P < 0.001$), overweight ($P < 0.001$), or obese ($P = 0.038$). Osteoporosis prevalence generally decreased with increasing altitude across these demographic groups, except among the elderly, where it increased. The prevalence of osteopenia decreased with altitude among females and across various BMI categories, but it increased among middle-aged and

Table 3 Differences in the Prevalence of Osteoporosis Among Population Subgroups with Different Characteristics at Different Altitudes

	Mid Altitude(N(%))			High Altitude(N(%))			*P**
	Normal Bone Density	**Osteopenia**	**Osteoporosis**	**Normal Bone Density**	**Osteopenia**	**Osteoporosis**	
Diagnosis	1101(54.10%)	408(20.05%)	526(25.85%)	11,442(70.72%)	332(16.28%)	265(13.00%)	<0.001
Sex							
Male	578(85.38%)	73(10.78%)	26(3.84%)	620(85.28%)	80(11.00%)	27(3.71%)	0.985
Female	523(38.51%)	335(24.67%)	500(36.82%)	822(62.65%)	252(19.21%)	238(18.14%)	<0.001
Age(Year)							
≤44	41(100.00%)	0(0%)	0(0%)	541(97.83%)	12(2.17%)	0(0%)	0.341
45–59	479(71.17%)	116(17.24%)	78(11.59%)	700(73.45%)	182(19.10%)	71(7.45%)	0.015
≥60	581(43.98%)	292(22.10%)	448(33.91%)	201(37.71%)	138(25.89%)	194(36.40%)	0.038
BMI(Kg/m^2)							
<18.5	36(58.06%)	10(16.13%)	16(25.81%)	41(82.00%)	6(12.00%)	3(6.00%)	0.011
18.5-23.9	562(55.04%)	204(19.98%)	255(24.98%)	549(73.49%)	106(14.19%)	92(12.32%)	<0.001
24–27.9	385(51.75%)	156(20.97%)	203(27.28%)	568(69.78%)	150(18.43%)	96(11.79%)	<0.001
≥28.0	118(56.73%)	38(18.27%)	52(25.00%)	284(66.36%)	70(16.36%)	74(17.29%)	0.038

Notes: Statistical analysis was performed using the R×C chi-square test. If more than 20% of the cells in the R×C table had expected counts less than 5, or if any cell had an expected count less than 1, the rank-sum test was applied. *For *P*-values less than 0.001, results are reported as *P*<0.001.

elderly individuals. No significant differences in osteoporosis incidence were observed among males ($P = 0.985$) or the younger age group ($P = 0.341$). For further details, refer to Table 3.

In the Kangting area, the prevalence of both osteopenia and osteoporosis was higher than in the Sertar area. Specifically, Kangting had an osteopenia prevalence of 18.10% and an osteoporosis prevalence of 14.26%, while Sertar showed osteopenia and osteoporosis prevalences of 6.54% and 6.23%, respectively. These disparities were statistically significant ($P < 0.001$). Significant variations in the prevalence of normal bone density, osteopenia, and osteoporosis were also observed among females ($P < 0.001$) and individuals categorized as normal weight ($P < 0.001$), overweight ($P < 0.001$), and obese ($P = 0.004$). The findings indicated that as altitude increased, the prevalence of both osteoporosis and osteopenia decreased. Conversely, within the Sertar cohort, middle-aged individuals ($P = 0.020$) experienced significantly higher rates of osteoporosis compared to those in Kangting, although the prevalence of osteopenia decreased. These differences were also statistically significant. No statistically significant differences were observed among males ($P = 0.083$) or those classified as underweight ($P = 0.158$). For a comprehensive view of the data, refer to Table 4.

Table 4 Differences in the Prevalence of Osteoporosis Among Population Subgroups with Different Characteristics in Different High-Altitude Areas (Kangting and Sertar)

	Kangting(N(%))			Sertar(N(%))			*P**
	Normal Bone Density	**Osteopenia**	**Osteoporosis**	**Normal Bone Density**	**Osteopenia**	**Osteoporosis**	
Diagnosis	1162(67.64%)	311(18.10%)	245(14.26%)	280(87.23%)	21(6.54%)	20(6.23%)	<0.001
Sex							
Male	460(83.18%)	70(12.66%)	23(4.16%)	160(91.95%)	10(5.75%)	4(2.30%)	0.083
Famel	702(60.26%)	241(20.69%)	222(19.06%)	120(81.63%)	11(7.48%)	16(10.88%)	<0.001
Age(Year)							
≤44	339(98.83%)	4(1.17%)	0(0%)	202(96.19%)	8(3.81%)	0(0%)	0.039
45–59	639(72.61%)	177(20.11%)	64(7.27%)	61(83.56%)	5(6.85%)	7(9.59%)	0.020
≥60	184(37.17%)	130(26.26%)	181(36.57%)	17(44.74%)	8(21.05%)	13(34.21%)	0.620

(*Continued*)

Table 4 (Continued).

	Kangting(N(%))			Sertar(N(%))			*P**
	Normal Bone Density	**Osteopenia**	**Osteoporosis**	**Normal Bone Density**	**Osteopenia**	**Osteoporosis**	
BMI(Kg/m^2)							
<18.5	34(82.93%)	4(9.76%)	3(7.32%)	7(77.78%)	2(22.22%)	0(0%)	0.158
18.5-23.9	453(71.11%)	100(15.70%)	84(13.19%)	96(87.27%)	6(5.45%)	8(7.27%)	<0.001
24–27.9	469(67.29%)	141(20.23%)	87(12.48%)	99(84.62%)	9(7.69%)	9(7.69%)	<0.001
≥28.0	206(60.06%)	66(19.24%)	71(20.70%)	78(91.76%)	4(4.71%)	3(3.53%)	0.004

Notes: Statistical analysis was performed using the R×C chi-square test. If more than 20% of the cells in the R×C table had expected counts less than 5, or if any cell had an expected count less than 1, the rank-sum test was applied. *For *P*-values less than 0.001, results are reported as *P*<0.001.

Discussion

The primary findings of this study indicate that the prevalence of both osteopenia and osteoporosis decreases with increasing altitude. Across all altitudes, females consistently exhibited higher rates of osteopenia and osteoporosis compared to males, with both conditions becoming more prevalent with advancing age. Additionally, underweight individuals in high-altitude regions had lower rates of osteopenia and osteoporosis compared to other BMI categories. Stratified analysis further revealed that osteoporosis prevalence was lower among females, middle-aged individuals, and across BMI categories in high-altitude regions, while it increased among the elderly. Similarly, the prevalence of osteopenia decreased among females and across different BMI categories. However, in the highest altitude regions, both osteopenia and osteoporosis showed further decreases among females and across different BMI categories, except for underweight individuals.

This study found an overall osteoporosis prevalence of 19.42% across three distinct altitudinal zones in Sichuan Province, western China. Notably, the prevalence in mid-altitude areas was 25.85%, significantly exceeding both the national average of 13.00% among Chinese adults aged 50 and above,[24] as well as the global prevalence estimate of 19.7%.[10] Conversely, the prevalence in the high-altitude regions of this study was reported at 13.00%, closely aligning with the national average but slightly below the global rate. A previous study on a multi-ethnic cohort in China reported that high altitudes could decrease bone density and increase the risk of osteoporosis,[25] which contrasts with the findings of this study. This discrepancy may be due to the use of a quantitative ultrasound bone densitometer in the previous study, a tool primarily used for screening rather than definitive diagnosis. In contrast, this study utilized DXA, the gold standard for diagnosing osteoporosis. Additionally, the average altitude in the high-altitude regions included in the previous study was 2503.50 ± 708.59 meters, whereas in this study, the high-altitude regions had significantly higher average elevations, such as Kangting at 2500 to 3000 meters and Sertar exceeding 4000 meters. This study highlights substantial differences in osteoporosis prevalence across various altitudes. In the following discussion, we explore potential factors contributing to the lower prevalence of osteoporosis in higher-altitude regions, including natural environmental conditions, lifestyle factors, and genetic influences.

The longer duration of sunlight exposure and better air quality in high-altitude regions are key factors contributing to the lower prevalence of osteoporosis. This study included two high-altitude areas with significant sunlight exposure: Kangting receives approximately 1900 to 2600 hours of sunshine annually,[26] while Sertar receives 2371 hours.[27] In contrast, the mid-altitude area of Mianzhu has a significantly lower average annual sunshine duration of only 1,011.3 hours.[28] This observation aligns with studies suggesting that prolonged sunlight exposure can significantly reduce the incidence of osteoporosis,[29] which corresponds with the lower incidence of osteoporosis observed in the higher-altitude Sertar compared to Kangting. The human body synthesizes vitamin D endogenously, with 7-dehydrocholesterol in the skin converting to vitamin D3 under ultraviolet (UV) radiation from sunlight. Factors such as season, duration of sunlight exposure, latitude, and the use of sunscreen can all influence vitamin D synthesis. In this study, the longer sunlight exposure in high-altitude regions presents a natural advantage in reducing osteoporosis risk. Environmental pollution may also be a critical factor influencing osteoporosis prevalence. According to information

from the Sichuan Provincial Office, the air quality in Ganzi Prefecture, where Kangting and Sertar are located, consistently ranks among the best in the province. In the January-June 2024 report, Ganzi ranked second in the provincial air quality index, while Deyang, where Mianzhu is located, ranked 13th.[30,31] Research has shown that environmental pollutants such as particulate matter (PM), nitrogen oxides (NOx, NO2), carbon monoxide, polychlorinated biphenyls (PCBs), phthalates, bisphenols, and heavy metals can adversely affect bone health through various mechanisms. These pollutants can disrupt hormonal balance, induce systemic inflammation, impair calcium metabolism, and interfere with the differentiation, proliferation, and function of bone cells, ultimately increasing the risk of skeletal diseases, including osteoporosis.[31]

It is essential to consider both lifestyle and genetic factors when exploring the differences in osteoporosis prevalence. In Mianzhu, over 95% of the population is Han Chinese, whereas in Kangting and Sertar, the population is predominantly Tibetan, comprising 78.97% of the inhabitants. The lifestyle differences between these groups are notable: Tibetans traditionally lead a nomadic lifestyle, with a diet rich in dairy products and meat, and a preference for alcohol and butter tea, while their intake of fruits and vegetables is limited due to resource constraints. In contrast, the diet in Mianzhu, influenced by Sichuan cuisine, is more diverse and characterized by heavy use of oil, spices, and chili. Studies have shown that the intake of various nutrients, including vitamin D, calcium, vegetables, fruits, legumes, nuts, dairy products, soy protein, and eggs, can affect the prevalence of osteoporosis.[32,33] Therefore, it is necessary to investigate the dietary patterns of Tibetan and Han populations in Sichuan, quantify their dietary components, and explore dietary compositions that may help prevent osteoporosis, with the aim of developing appropriate intervention policies. Physical activity may also play a critical role. The Tibetan population, known as "the people on horseback", leads a physically active lifestyle, which may influence the prevalence of osteoporosis—this warrants further investigation. From a genetic perspective, Tibetans are considered an ethnic minority in China. Recent studies have revealed that Tibetans and Han Chinese shared common ancestry approximately 5000 years ago, but genetic adaptations to the environment have since occurred. Future research may identify genetic loci associated with osteoporosis that differ between these populations, shedding light on the role of genetics in the disease's prevalence.[34]

Surprisingly, further analysis revealed that the prevalence of osteoporosis in females in mid-altitude areas was nearly double that of females in high-altitude areas, whereas the prevalence in males was not affected by altitude. This suggests that altitude-related factors have minimal impact on males; however, for females, increased sunlight exposure and dietary adjustments, along with other modifiable factors may help reduce the risk of osteoporosis. Future research should focus more on female osteoporosis patients, and targeted strategies should be developed to aid in the prevention of osteoporosis in the Sichuan region.[35] Additionally, it is crucial to investigate the reasons behind the differences in osteoporosis prevalence between different altitudes and between sexes in future studies. Previous research has indicated that being overweight or obese can reduce the risk of developing osteoporosis by 48.6% and 70.1%, respectively, while individuals with low body weight are at heightened risk for the condition.[36,37] However, this study did not replicate those findings. Nonetheless, it found that individuals with varying BMIs at lower altitudes had higher rates of osteoporosis compared to their counterparts at higher altitudes. This suggests that certain altitude-related factors may play a critical role in preventing osteoporosis across different BMI categories.

The primary strength of this study is its analysis of the differences in osteoporosis prevalence among various demographic groups across different altitudes in western China, a topic that has been scarcely explored in previous research. This provides essential reference information for developing future intervention strategies. However, the main limitation of this study is the lack of an in-depth analysis of the factors contributing to the differences in osteoporosis incidence among these altitudinal populations. Addressing this gap will be a key focus of future research.

Conclusion

This study demonstrates that higher altitudes are associated with a decreased prevalence of osteopenia and osteoporosis, particularly among females and middle-aged individuals. These findings highlight the need for region-specific strategies to prevent osteoporosis.

Data Sharing Statement

The datasets generated and/or analysed during the current study are not publicly available but are available from the corresponding author on reasonable request.

Ethics Approval and Informed Consent

The West China Hospital, Sichuan University's Ethics Committee, granted ethical approval for this study (Approval No. 2019(145)).

Author Contributions

Rong Yang and Qing Ma are co-first authors: Qing Ma, Supervisor Nurse. All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors declare that they have no competing interests.

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