

Original Research Article

EVALUATE THE ASSOCIATION BETWEEN VITAMIN D AND BONE MINERAL DENSITY AMONG POSTMENOPAUSAL WOMEN: A PROSPECTIVE OBSERVATIONAL STUDY

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ABSTRACT

Background: Vitamin D plays a crucial role in calcium homeostasis and bone metabolism, and its deficiency is common among postmenopausal women. The relationship between serum vitamin D levels and bone mineral density (BMD), however, remains inconsistent across studies, particularly in apparently healthy postmenopausal women. The objective is to evaluate serum 25-hydroxyvitamin D [25(OH)D] levels in postmenopausal women and to assess their association with bone mineral density at the lumbar spine and femoral neck, as well as with dietary calcium intake and sunlight exposure.

Materials and Methods: This prospective observational study included 120 healthy postmenopausal women who attained menopause naturally. Serum biochemical parameters including serum calcium, phosphorus, albumin, and 25(OH)D were measured. Bone mineral density was assessed at the lumbar spine (L2–L4) and femoral neck using dual-energy X-ray absorptiometry (DEXA). Vitamin D status was categorized as deficient (<20 ng/mL), insufficient (20–30 ng/mL), and sufficient (>30 ng/mL). Statistical analysis was performed using descriptive statistics and Pearson's correlation coefficient, with $P < 0.05$ considered statistically significant.

Results: Vitamin D deficiency and insufficiency were highly prevalent among the study population. Although mean BMD and T-scores at the lumbar spine and femoral neck were lower in women with vitamin D deficiency, the differences across vitamin D categories were not statistically significant ($P > 0.05$). No significant correlation was observed between serum 25(OH)D levels and BMD at the femoral neck or lumbar spine. However, serum vitamin D levels showed a significant positive correlation with dietary calcium intake and duration of sunlight exposure, and a significant negative correlation with years since menopause.

Conclusion: The study highlights a high prevalence of hypovitaminosis D among postmenopausal women. While serum vitamin D levels were not independently associated with bone mineral density, adequate vitamin D status was positively influenced by dietary calcium intake and sunlight exposure. Routine screening and early correction of vitamin D deficiency may support overall bone health and complement osteoporosis prevention strategies in postmenopausal women.

Keywords: Vitamin D; Bone mineral density; Postmenopausal women; Osteoporosis; Calcium intake; Sunlight exposure

INTRODUCTION

Postmenopausal osteoporosis is a major public health concern worldwide and represents a leading cause of morbidity, disability, and reduced quality of life among aging women. The decline in estrogen levels following menopause results in accelerated bone resorption, progressive reduction in bone mineral density (BMD), and increased susceptibility to fragility fractures, particularly at the hip, spine, and wrist.^[1-3] With increasing life expectancy, the burden of osteoporosis-related fractures is expected to rise substantially, especially in developing countries where screening and preventive strategies remain suboptimal.^[4]

Vitamin D plays a pivotal role in skeletal health by regulating intestinal calcium absorption, maintaining calcium and phosphate homeostasis, and modulating bone remodeling.^[5] Deficiency of vitamin D leads to reduced calcium absorption, secondary hyperparathyroidism, increased bone turnover, and subsequent bone loss.^[6] In postmenopausal women, who already experience estrogen-deficient bone resorption, inadequate vitamin D status may further aggravate skeletal fragility and compromise peak bone mass maintenance.^[7]

Despite abundant sunlight in many regions, vitamin D deficiency and insufficiency are widely prevalent across different populations, including tropical and subtropical countries.^[8] Factors such as reduced cutaneous synthesis with advancing age, limited outdoor activity, skin pigmentation, clothing practices, dietary inadequacy, and lack of food fortification contribute to low serum 25-hydroxyvitamin D [25(OH)D] levels in postmenopausal women.^[9] Several population-based studies have reported a high prevalence of hypovitaminosis D even among apparently healthy women, raising concerns about its silent contribution to osteoporosis risk.^[10]

The relationship between serum vitamin D levels and bone mineral density, however, remains inconsistent across studies. While some investigators have demonstrated a positive association between higher serum 25(OH)D levels and BMD at the hip and spine, others have failed to observe a significant correlation, particularly after adjusting for confounding factors such as age, body mass index, and calcium intake.^[11] These discrepancies may be attributed to differences in study design, ethnic variations, sample size, skeletal sites assessed, and categorization of vitamin D status.

Given these uncertainties and the limited region-specific data available, especially among Indian postmenopausal women, the present study was undertaken to evaluate serum 25(OH)D levels and their association with bone mineral density at the lumbar spine and femoral neck. In addition, the study aimed to explore the relationship between vitamin D status and lifestyle-related factors such as dietary calcium intake and sunlight exposure, thereby contributing to a better understanding of vitamin D–bone interactions in postmenopausal women.

AIM

To evaluate the relationship between serum 25-hydroxyvitamin D levels and bone mineral density in healthy postmenopausal women.

Objectives

1. To assess the association between serum 25-hydroxyvitamin D levels and bone mineral density at the neck of femur and lumbar spine in postmenopausal women.
2. To examine the relationship between serum 25-hydroxyvitamin D levels and lifestyle-related factors, including dietary calcium intake and duration of sunlight exposure, in postmenopausal women.

MATERIALS AND METHODS

This prospective observational study included 120 healthy postmenopausal women who attained menopause naturally. Serum biochemical parameters including serum calcium, phosphorus, albumin, and 25(OH)D were measured. Bone mineral density was assessed at the lumbar spine (L2–L4) and femoral neck using dual-energy X-ray absorptiometry (DEXA). Vitamin D status was categorized as deficient (<20 ng/mL), insufficient (20–30 ng/mL), and sufficient (>30 ng/mL). Statistical analysis was performed using descriptive statistics and Pearson's correlation coefficient, with $P < 0.05$ considered statistically significant.

RESULTS

A total of 120 healthy postmenopausal women were included in the study. Participants were categorized based on serum 25-hydroxyvitamin D [25(OH)D] levels into deficient ($n = 56$), insufficient ($n = 38$), and sufficient ($n = 26$) groups. Baseline demographic characteristics, biochemical parameters, bone mineral density measurements, and their relationship with vitamin D status were analyzed.

Table 1: Relationship of certain variables by Vitamin D categorization

Parameter (mean ± SE)	Deficient (56)	Insufficient (38)	Sufficient (26)	P value & significance
Age (years)	65.6 ± 0.51	59.4 ± 0.82	50.2 ± 0.56	F = 89.2; *P < 0.001; S
Duration of menopause (years)	12.9 ± 0.74	7.7 ± 0.88	3.0 ± 0.26	F = 31.4; *P < 0.001; S
BMI (kg/m ²)	27.3 ± 0.58	29.3 ± 0.79	26.3 ± 0.88	F = 3.62; *P = 0.03; S
Dietary calcium intake (mg/day)	492.6 ± 21.4	581.2 ± 98.6	691.4 ± 158.2	F = 18.3; *P < 0.001; S
BMD – neck of femur (g/cm ²)	0.63 ± 0.03	0.66 ± 0.03	0.65 ± 0.04	F = 0.29; P = 0.74; NS
BMD – lumbar spine (g/cm ²)	0.63 ± 0.02	0.65 ± 0.02	0.65 ± 0.03	F = 0.31; P = 0.73; NS
T-score at hip	-2.03 ± 0.14	-1.78 ± 0.12	-1.92 ± 0.21	F = 0.71; P = 0.49; NS
T-score at lumbar spine	-1.90 ± 0.11	-1.77 ± 0.11	-1.86 ± 0.16	F = 0.24; P = 0.78; NS

[Table 1] shows the relationship between selected demographic, clinical, and bone parameters across vitamin D categories. The mean age was significantly higher in the vitamin D-deficient group (65.6 ± 0.51 years) compared to the insufficient (59.4 ± 0.82 years) and sufficient groups (50.2 ± 0.56 years) ($P < 0.001$). Similarly, the mean duration since menopause was longest among women with vitamin D deficiency (12.9 ± 0.74 years) followed by the insufficient (7.7 ± 0.88 years) and sufficient groups (3.0 ± 0.26 years), and this difference was statistically significant ($P < 0.001$).

The mean BMI was significantly higher in the vitamin D-insufficient group (29.3 ± 0.79 kg/m²) compared to the deficient (27.3 ± 0.58 kg/m²) and sufficient groups (26.3 ± 0.88 kg/m²) ($P = 0.03$).

Dietary calcium intake increased progressively across categories, being lowest in the deficient group (492.6 ± 21.4 mg/dl) and highest in the sufficient group (691.4 ± 158.2 mg/dl), with a statistically significant difference ($P < 0.001$).

The mean BMD at the neck of femur (0.63 ± 0.03 , 0.66 ± 0.03 , and 0.65 ± 0.04 g/cm²) and lumbar spine (0.63 ± 0.02 , 0.65 ± 0.02 , and 0.65 ± 0.03 g/cm²) were comparable across deficient, insufficient, and sufficient groups, respectively, with no statistically significant differences ($P > 0.05$). Similarly, the mean T-scores at the hip (-2.03 ± 0.14 , -1.78 ± 0.12 , -1.92 ± 0.21) and lumbar spine (-1.90 ± 0.11 , -1.77 ± 0.11 , -1.86 ± 0.16) did not differ significantly among the groups ($P > 0.05$).

Table 2: Vitamin D categorization by Bone Mineral Density at the level of hip

Vitamin D category	No. of subjects	Normal	Osteopenia	Osteoporosis
Deficient	56	12 (21.4%)	26 (46.4%)	18 (32.2%)
Insufficient	38	9 (23.7%)	23 (60.5%)	6 (15.8%)
Sufficient	26	5 (19.2%)	16 (61.6%)	5 (19.2%)
Total	120	26 (21.7%)	65 (54.2%)	29 (24.1%)

$\chi^2 = 3.68$; $P = 0.45$; NS

Values in parentheses indicate percentages.

[Table 2] depicts the distribution of bone mineral density categories at the hip across vitamin D status. The proportion of osteoporosis at the hip was highest in the vitamin D-deficient group (18 of 56; 32.2%) compared to the insufficient (6 of 38; 15.8%) and sufficient groups (5 of 26; 19.2%). Osteopenia was

the most common finding across all categories, observed in 46.4% of deficient, 60.5% of insufficient, and 61.6% of sufficient participants. However, the overall distribution of hip BMD categories across vitamin D groups was not statistically significant ($\chi^2 = 3.68$; $P = 0.45$).

Table 3: Vitamin D categorization by Bone Mineral Density at the level of lumbar spine

Vitamin D category	No. of subjects	Normal	Osteopenia	Osteoporosis
Deficient	56	12 (21.4%)	28 (50.0%)	16 (28.6%)
Insufficient	38	6 (15.8%)	26 (68.4%)	6 (15.8%)
Sufficient	26	4 (15.4%)	16 (61.5%)	6 (23.1%)
Total	120	22 (18.3%)	70 (58.3%)	28 (23.4%)

$\chi^2 = 3.21$; $P = 0.62$; NS

[Table 3] presents the relationship between vitamin D status and lumbar spine BMD. Osteoporosis at the lumbar spine was most frequent in the vitamin D-deficient group (16 of 56; 28.6%) compared to the insufficient (6 of 38; 15.8%) and sufficient groups (6 of 26; 23.1%). Osteopenia constituted the predominant category across all vitamin D groups, accounting for 50.0% of deficient, 68.4% of insufficient, and 61.5% of sufficient women. Despite these trends, the association between vitamin D status and lumbar spine BMD category was not statistically significant ($\chi^2 = 3.21$; $P = 0.62$).

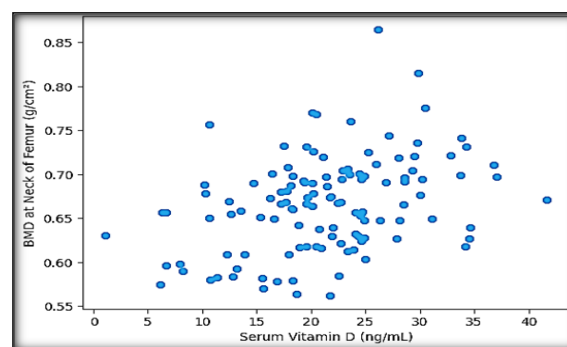


Figure 1: Correlation analysis between serum Vitamin D and bone mineral density at the neck of femur.

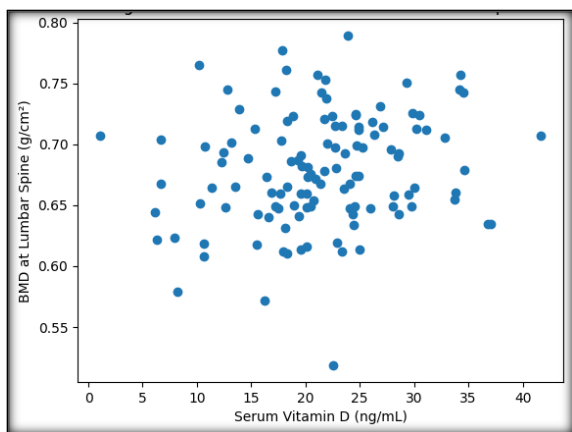


Figure 2: Correlation analysis between serum Vitamin D and bone mineral density at the lumbar spine.

Correlation analysis

Correlation analysis showed no significant association between serum 25(OH)D levels and BMD at the neck of femur ($r = 0.12$; $P = 0.26$) or at the lumbar spine ($r = 0.10$; $P = 0.33$). However, serum 25(OH)D levels demonstrated a significant positive correlation with dietary calcium intake ($r = 0.49$; $P < 0.001$) and duration of sunlight exposure ($r = 0.73$; $P < 0.001$). A significant negative correlation was observed between serum 25(OH)D levels and years since menopause ($r = -0.60$; $P < 0.001$).

Scatter plot showing the relationship between serum 25-hydroxyvitamin D levels and bone mineral density at the neck of femur in postmenopausal women. A weak positive correlation was observed, which was not statistically significant ($r = 0.12$; $P = 0.26$).

Scatter plot depicting the correlation between serum 25-hydroxyvitamin D levels and bone mineral density at the lumbar spine. The association was weak and did not reach statistical significance ($r = 0.10$; $P = 0.33$).

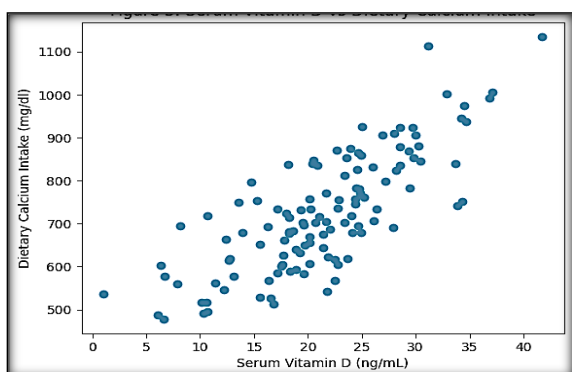


Figure 3: Correlation analysis between serum Vitamin D and dietary calcium intake in all study subjects.

Scatter plot demonstrating a significant positive correlation between serum 25-hydroxyvitamin D levels and dietary calcium intake among postmenopausal women ($r = 0.49$; $P < 0.001$).

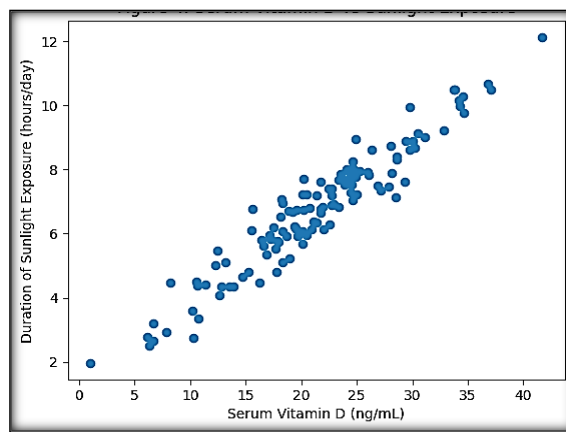


Figure 4: Correlation analysis between serum Vitamin D and duration of sunlight exposure in all study subjects.

Scatter plot showing a strong positive correlation between serum 25-hydroxyvitamin D levels and duration of daily sunlight exposure ($r = 0.73$; $P < 0.001$).

DISCUSSION

This prospective observational study in healthy postmenopausal women ($n = 120$) evaluated the association of serum 25(OH)D with bone mineral density at the neck of femur and lumbar spine, and its relationship with lifestyle determinants. The principal observations were: (i) serum 25(OH)D showed weak, non-significant correlations with BMD at the neck of femur and lumbar spine; (ii) the vitamin D-deficient group showed numerically higher osteoporosis proportions at both hip and lumbar spine, but between-group differences were not statistically significant; and (iii) serum 25(OH)D correlated positively with dietary calcium intake and sunlight exposure and negatively with years since menopause. These findings are compared below with available evidence.

Vitamin D status: high prevalence of insufficiency/deficiency in postmenopausal women. Large datasets consistently show that vitamin D insufficiency and deficiency are common in postmenopausal women. In the Shanghai real-world cohort ($n = 8,532$), mean serum 25(OH)D was ~ 22 ng/mL, and deficiency/insufficiency together accounted for the majority (Chen et al., 2024).^[12] Supporting this, a multicenter Chinese study of 1,674 postmenopausal women reported mean 25(OH)D of 18.0 ± 8.4 ng/mL, with 91.2% < 30 ng/mL and 61.3% < 20 ng/mL (Xie et al., 2018).^[13] In a Shanghai suburban cohort ($n = 5,067$), mean 25(OH)D was 24.5 ± 13.2 ng/mL, with 37.7% insufficiency and 30.5% deficiency (Gao et al., 2017).^[14] Additional community data from Shanghai postmenopausal women reported a mean 25(OH)D around 17.09 ng/mL with high combined prevalence of insufficiency/deficiency (Zhang et al., 2011).^[15]

In our cohort, vitamin D-deficient women were older and had longer duration since menopause than the

insufficient and sufficient groups [Table 1]. This directionality is compatible with age-related decline in cutaneous synthesis and cumulative menopausal duration effects, though across studies the age–vitamin D relationship is not always uniform. For example, in a Brazilian postmenopausal cohort (n = 250), vitamin D levels did not differ significantly across age groups despite widespread insufficiency/deficiency (Labronici et al., 2013).^[16] This suggests that local lifestyle, clothing, diet, and sun exposure behaviors may strongly influence vitamin D across age strata.

Vitamin D and BMD: why significant relationships may appear in large cohorts but not in smaller samples

In the present study, serum 25(OH)D demonstrated weak, non-significant correlations with BMD at the neck of femur ($r = 0.12$; $P = 0.26$) and lumbar spine ($r = 0.10$; $P = 0.33$). This “low-effect” pattern is consistent with the broader literature that reports controversial vitamin D–BMD relationships in postmenopausal women, with some studies detecting positive associations at femoral neck and/or hip and others reporting no significant association.

In Chen et al.’s large dataset, higher 25(OH)D levels were associated with modestly higher BMD at key sites, including femoral neck and total hip (and lumbar spine in osteoporosis), but the reported correlation coefficients were small (e.g., $r \approx 0.04$ – 0.05 for hip sites in osteoporosis), highlighting that statistically significant findings in large samples may still represent limited clinical effect size (Chen et al., 2024).^[12] Similar site-focused positive associations were referenced in southern Chinese postmenopausal women (Deng et al., 2015),^[17] and in Japanese postmenopausal cohorts where higher vitamin D was linked with greater femoral neck BMD (Nakamura et al., 2008).^[18] Yoshimura and colleagues reported that higher serum 25(OH)D may prevent osteoporosis at the femoral neck but not necessarily at L2–L4, emphasizing site differences (Yoshimura et al., 2015).^[19]

Conversely, null findings have also been reported. In a healthy postmenopausal cohort from the OFELY study, 25(OH)D was not consistently related to hip BMD (Garnero et al., 2007),^[20] and in the Brazilian study, vitamin D did not significantly differ across BMD categories (Labronici et al., 2013).^[16] Therefore, our null correlation is plausible, particularly because BMD is influenced by multiple factors beyond vitamin D, and the detectable independent effect of 25(OH)D may be small without large sample sizes or stratified adjustment.

Vitamin D and osteoporosis risk by skeletal site: femur/femoral neck often shows stronger signal than lumbar spine

In our study, osteoporosis proportions were numerically higher in the vitamin D–deficient group at both hip and lumbar spine [Tables 2 and 3], but the association was not statistically significant. This direction is broadly consistent with population-based

findings that higher vitamin D status may be protective, especially at femoral sites.

The NHANES-based analysis reported that higher serum 25(OH)D categories were associated with lower odds of osteoporosis, with clearer protection at total femur and femoral neck than at lumbar spine in the fully adjusted model (Wang & Yang, 2023).^[21] Their discussion also notes that site-specific differences may reflect cortical versus trabecular composition and the interplay of vitamin D with calcium absorption and PTH-mediated remodeling (Wang & Yang, 2023).^[21] This is compatible with the pattern referenced in earlier work, where femoral neck BMD improved with vitamin D supplementation but lumbar BMD showed less change in some settings (Burger et al., 1994).^[22] Pasco et al. reported that lumbar and hip BMD were more likely normal in women with higher 25(OH)D levels than in those with low levels, supporting a broader bone-health signal across sites in some cohorts (Pasco et al., 2009).^[23]

Taken together, the international evidence suggests that protective signals may be modest, site-dependent, and stronger in older age groups or larger samples, which can explain why our categorical differences remain non-significant despite numerically higher osteoporosis proportions in the deficient category.

Vitamin D, PTH and bone turnover markers: relevance and limitation for the present study

Our study did not measure PTH or bone turnover markers (BTMs); therefore, direct comparison is limited. However, mechanistic and clinical datasets consistently report that vitamin D deficiency can be accompanied by higher PTH and increased bone turnover, contributing to bone loss. Chen et al. demonstrated negative associations between 25(OH)D and PTH/BTMs (β -CTX, osteocalcin) in both osteopenia and osteoporosis groups, with lower PTH and turnover markers at higher 25(OH)D levels (Chen et al., 2024).^[12] Randomized trial evidence also supports that vitamin D supplementation can reduce BTMs such as P1NP and β -CTX in postmenopausal women with low bone mass (Grimnes et al., 2012).^[24] Mechanistically, this aligns with the understanding that vitamin D deficiency reduces active vitamin D metabolite availability, raising PTH, which increases bone turnover and resorption (Lips & van Schoor, 2011).^[25] In postmenopausal women, estrogen deficiency itself accelerates bone turnover, making BTMs and PTH particularly relevant covariates when interpreting BMD relationships (Khosla & Monroe, 2018).^[26] Accordingly, the absence of PTH/BTM data is an important limitation in interpreting whether vitamin D status in our cohort primarily reflects lifestyle exposure or also reflects altered bone turnover pathways.

Lifestyle determinants: sunlight exposure and dietary calcium track strongly with vitamin D status.

In our cohort, 25(OH)D correlated significantly with dietary calcium intake ($r = 0.49$; $P < 0.001$) and daily

sunlight exposure ($r = 0.73$; $P < 0.001$). This is biologically coherent because vitamin D status is determined by both cutaneous synthesis and dietary contribution. However, even substantial sun exposure does not guarantee sufficiency; in young adults from sunny settings, low vitamin D levels have been reported despite high sun exposure (Binkley et al., 2007).^[27] Seasonal variation can also influence vitamin D status, with higher levels in summer months compared to winter months, as discussed in NHANES-based findings (Wang & Yang, 2023),^[21] and in earlier observational data on seasonal variation of plasma 25-OH vitamin D (MacDonald & Swaminathan, 1988).^[28] Seasonal effects on BMD and calciotropic hormones have also been described, with lower BMD reported in winter compared with summer in elderly women (Rosen et al., 1994).^[29] These observations reinforce that the strong vitamin D–sunlight correlation in our data is expected, while

the vitamin D–BMD correlation may remain weak due to the multi-determinant nature of BMD.

Years since menopause: key confounder and effect modifier

We observed a significant negative correlation between serum 25(OH)D and years since menopause ($r = -0.60$; $P < 0.001$), and the vitamin D–deficient group had the longest menopausal duration [Table 1]. This is important because years since menopause strongly relates to bone loss trajectories and may confound cross-sectional vitamin D–BMD relationships. In fully adjusted population models, years since menopause is frequently included as an adjustment variable, and protective effects of higher vitamin D become more apparent in older women (Wang & Yang, 2023).^[21] Our finding supports that menopausal duration should be treated as a central covariate when interpreting vitamin D and bone outcomes.

Comparison Tables

A) Vitamin D status prevalence / baseline pattern (Table 1 context)

Parameter	Present study (n=120)	Shanghai real-world (Chen et al., 2024)	Multicenter China (Xie et al., 2018)	Shanghai suburban (Gao et al., 2017)	Shanghai community (Zhang et al., 2011)	Brazil (Labronici et al., 2013)
Vitamin D distribution	Categorized: deficient/insufficient/sufficient	Deficiency 46.6%, insufficiency 34.5% (12)	91.2% <30; 61.3% <20 (13)	37.7% insufficient; 30.5% deficient (14)	Mean ~17.09 ng/mL; high low-D burden (15)	>70% low D in each age group; no age-group difference (16)

B) Vitamin D vs BMD correlation / mean differences (Figures 1 & 2; Table 1 BMD rows)

Site	Present study	Chen et al., 2024	Deng et al., 2015	Nakamura et al., 2008	Yoshimura et al., 2015	Garnero et al., 2007	Labronici et al., 2013
Femoral neck	Weak +, NS (r=0.12)	Positive, small effect; significant in large sample (12)	Positive association reported (17)	Higher Vit D linked with higher FN BMD (18)	Protective at FN more than L2–4 (19)	Not consistently related to hip BMD (20)	No significant association (16)
Lumbar spine	Weak +, NS (r=0.10)	Trend toward higher LS BMD in osteoporosis group (12)	Not specified here	Not specified	Less consistent at L2–4 (19)	Not emphasized	No significant association (16)

C) Vitamin D category vs osteoporosis/osteopenia distribution (Tables 2 & 3)

Outcome	Present study	Chen et al., 2024	Wang & Yang, 2023 (NHANES)	Pasco et al., 2009	Labronici et al., 2013
Hip osteoporosis vs Vit D	Higher % in deficient; NS	Higher Vit D associated with slightly higher hip BMD; distributions similar (12)	Higher Vit D protective for total femur/femoral neck osteoporosis (21)	Higher Vit D associated with more normal hip/lumbar BMD (23)	No association between Vit D and BMD categories (16)
Lumbar osteoporosis vs Vit D	Higher % in deficient; NS	Higher Vit D associated with higher LS BMD in osteoporosis (12)	LS protection weaker/not consistent after full adjustment (21)	Higher Vit D associated with more normal lumbar BMD (23)	No association (16)

D) Lifestyle correlations (Figures 3 & 4)

Relationship	Present study	Supporting/related evidence from pasted content
Vit D vs dietary calcium	Positive, significant (r=0.49)	Chen et al. note lifestyle variables like daily calcium intake may be missing in EHR and are relevant confounders (12).
Vit D vs sunlight exposure	Strong positive, significant (r=0.73)	Low Vit D can occur despite high sun exposure (Binkley et al., 2007) (27); seasonal variation influences Vit D (MacDonald & Swaminathan, 1988) (28) and may influence BMD patterns (Rosen et al., 1994) (29).

Limitations: The study's cross-sectional design limits causal inference between serum vitamin D levels and bone mineral density, and unmeasured factors such as physical activity and parathyroid hormone levels may have influenced the results.

CONCLUSION

The present study demonstrates a high prevalence of vitamin D deficiency and insufficiency among postmenopausal women, despite the inclusion of apparently healthy individuals. Although serum 25-hydroxyvitamin D levels did not show a statistically significant direct correlation with bone mineral density at the lumbar spine or femoral neck, women with lower vitamin D levels consistently exhibited lower mean BMD values and T-scores, indicating a trend toward poorer bone health.

A significant positive association was observed between serum vitamin D levels and dietary calcium intake as well as duration of sunlight exposure, highlighting the importance of lifestyle factors in maintaining adequate vitamin D status. Additionally, serum vitamin D levels showed a negative association with increasing years since menopause, emphasizing the cumulative effect of menopausal duration on vitamin D status and bone health.

The findings suggest that while vitamin D alone may not be a strong independent determinant of bone mineral density, adequate vitamin D status may contribute to the preservation of bone mass and slowing of age-related bone loss, particularly when combined with sufficient calcium intake and regular sunlight exposure. These results reinforce the need for routine screening of vitamin D levels in postmenopausal women, even in the absence of overt osteoporosis.

Early identification and correction of vitamin D deficiency, along with lifestyle modification, may play a supportive role in comprehensive osteoporosis prevention strategies. Longitudinal studies with larger sample sizes and intervention-based designs are warranted to further clarify the causal relationship between vitamin D status and skeletal health in postmenopausal women.

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