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Research Article

Role of Micronutrients in Maintaining Bone Health and Reducing Long-Term Health Risks among Postmenopausal Women

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ABSTRACT

Background: Postmenopausal women are at increased risk of micronutrient deficiency, reduced bone mineral density, osteoporosis, falls, and fragility fractures due to estrogen decline, aging, dietary inadequacy, and reduced physical activity.

Objective: To assess the contribution of micronutrients to bone health and the prevention of long-term health risks in post-menopausal women.

Methods: This cross-sectional analytical study was conducted from January 2024 to August 2025 at the Department of Gynaecology and Obstetrics, KRL Hospital, Islamabad, Pakistan, in collaboration with Shaikh Zayed Medical College, Rahim Yar Khan, Pakistan. A total of 130 postmenopausal women were enrolled. Demographic, dietary, clinical history, serum micronutrient, and bone mineral density were measured. The levels of serum vitamin D, calcium, magnesium, zinc, alkaline phosphatase, and parathyroid hormone (PTH) were determined. Bone mineral density was evaluated using dual-energy X-ray absorptiometry.

Results: The mean age was 59.4 ± 7.1 years, and the mean duration since menopause was 9.2 ± 5.6 years. Vitamin D deficiency was found in 78 (60.0%) women, calcium insufficiency in 52 (40.0%), magnesium deficiency in 44 (33.8%), and zinc deficiency in 49 (37.7%). Osteopenia was present in 55 (42.3%) participants, while osteoporosis was observed in 39 (30.0%). Osteoporosis was significantly more frequent among women with vitamin D deficiency (42.3%), calcium insufficiency (46.2%), magnesium deficiency (45.5%), and zinc deficiency (44.9%). A single micronutrient deficiency was independently associated with osteoporosis, with an adjusted OR of 4.18 (95% CI: 1.81–9.67, p<0.001).

Conclusion: Micronutrient deficiencies were common among postmenopausal women and were significantly associated with osteoporosis and long-term skeletal health risks.

Keywords: Micronutrients, Postmenopausal Women, Osteoporosis, Bone Mineral Density, Vitamin D, Calcium.

INTRODUCTION

Postmenopausal women are at increased risk of impaired bone health due to hormonal, nutritional, metabolic, and age-related changes[1]. With menopause and the decrease in estrogen, the bone remodeling process speeds up and bone resorption increases, leading to a progressive loss of bone mineral density[2]. Consequently, osteopenia, osteoporosis, fragility fractures, chronic musculoskeletal pain, and functional limitation are important long-term health issues among this population. Such complications can have a significant impact on quality of life, and the associated morbidity and dependency, as well as frequent hospital appointments and fracture-related issues, can also strain healthcare systems[3].

Bone is a metabolically active tissue and is continually remodeled throughout life[4]. This remodeling process requires sufficient amounts of essential micronutrients that are needed to support bone mineralization, collagen

formation, osteoblast function, neuromuscular coordination, and calcium–phosphorus balance[5]. Among these nutrients, vitamin D and calcium are most widely recognized for their role in maintaining bone strength; however, other micronutrients such as magnesium, phosphorus, zinc, vitamin K, and trace minerals also contribute significantly to skeletal integrity. Low or insufficient intakes of these micronutrients may lead to poor bone quality without clinical signs[6].

Vitamin D has a pivotal role in calcium absorption, bone mineralization, and serum calcium homeostasis[7]. Postmenopausal women are often recognized to have low levels of vitamin D because of decreased vitamin D production in the skin, limited sun exposure, dietary vitamin D deficiency, obesity, and metabolic changes associated with aging. Low vitamin D levels may cause secondary hyperparathyroidism, high bone turnover, low bone mineral density, weakness of the proximal muscles, and an increase in falls and fractures[8]. Likewise, less calcium means more progressive loss of calcium from the bones, especially if the calcium intake is not high enough to compensate for the higher demand of older women[9].

Another micronutrient that plays a key role in bone metabolism is magnesium. It affects the activation of vitamin D, the regulation of parathyroid hormone, formation of hydroxyapatite crystals[10]. Low magnesium levels can affect calcium metabolism and lead to weak bones. Zinc participates in osteoblast activity, collagen synthesis, and repair of bone tissue; vitamin K in the carboxylation of osteocalcin, a protein necessary for proper bone mineral binding. So, thinking about bone health in terms of calcium and vitamin D only is too narrow-minded; it's a result of many micronutrient interactions[11].

Micronutrient deficiencies are not just a problem for osteoporosis. The suboptimal micronutrient status can lead to an increased risk of falls, frailty, sarcopenia, impaired wound healing, chronic pain, metabolic dysfunction, and decreased physical performance[12]. These risks can also add up over time and be a factor in morbidity in postmenopausal women. Identification of nutritional deficiency early on can then provide a chance for preventative intervention before irreversible skeletal damage or fracture occurs[13].

While micronutrient needs are well recognized, there is still a lack of awareness about micronutrient nutrition and micronutrient screening among post-menopausal women[14]. Other factors such as dietary patterns, socioeconomic status, restricted outdoor activity, obesity, comorbid diseases, and supplementation intake could also impact micronutrient status. Evaluation of these factors is crucial in formulating prevention strategies geared towards bone health and decreasing long-term complications[15].

The purpose of the present study was to investigate the importance of micronutrients in maintaining bone health and preventing long-term health risks among women after menopause. This study will evaluate the relationship between nutritional adequacy and skeletal health in this vulnerable population by measuring serum micronutrient status, nutrition intake, bone mineral density, and clinical outcomes. The findings may help guide early screening, nutritional counseling, supplementation strategies, and preventive healthcare planning for postmenopausal women[16].

MATERIALS AND METHODS

This was a cross-sectional analytical study to assess the importance of micronutrients for bone health and long-term health risks in postmenopausal women. The study was conducted from January 2024 to August 2025 at the Department of Gynaecology and Obstetrics, KRL Hospital, Islamabad, Pakistan, in collaboration with Shaikh Zayed Medical College, Rahim Yar Khan, Pakistan.

There were 130 post menopausal women selected with a non-probability consecutive sampling technique. Postmenopausal women ages 45–75 years, with no menstruation for at least 12 months, were recruited after signing a written informed consent. Women who were willing to participate in clinical evaluation, dietary assessment, laboratory investigations, and bone mineral density assessment were included in the study.

Those who had undergone a surgical menopause, suffered from a premature menopause, chronic kidney disease, chronic liver disease, malignancy, thyroid or parathyroid disease, chronic inflammatory diseases, long-term corticosteroid therapy, hormone replacement therapy, anti-osteoporotic therapy, or known metabolic bone disease, except osteoporosis, were excluded. Participants with incomplete data or unwillingness to participate were also excluded from the study.

A structured proforma was used for collecting demographic and clinical data. Age, body mass

index, age at menopause, parity, dietary habits, sun exposure, physical activity, history of falls, fragility fractures, chronic musculoskeletal pain, comorbidities, medication use, and supplementation history were all assessed. Standard methods were used to measure height and weight, and body mass index (BMI) was calculated as weight (kg)/height (m2).

A food frequency questionnaire and a 24-hour dietary recall were used to evaluate dietary micronutrient intakes. Calcium intake was assessed for calcium-rich foods, vitamin D-fortified foods, dairy foods, eggs, fish, green leafy vegetables, nuts, and legumes. Dietary intake was grouped as adequate or inadequate based on the age-appropriate nutritional requirements.

Biochemical analysis of the blood was performed using venous blood samples taken under aseptic conditions. Laboratory parameters (serum 25-hydroxy vitamin D, calcium, phosphorus, magnesium, zinc, alkaline phosphatase, and parathyroid hormone) were determined by routine laboratory methods. Deficiency of vitamin D and other micronutrients was defined using laboratory reference values.

Dual-energy X-ray absorptiometry was used to measure bone mineral density at the lumbar spine and at the femoral neck. These were divided into three groups based on T scores: normal bone density, osteopenia, and osteoporosis. A T-score of −1.0 or above was considered normal, between −1.0 and −2.5 was categorized as osteopenia, and −2.5 or below was categorized as osteoporosis.

Bone health status using bone mineral density was the primary outcome variable. Secondary outcomes were the prevalence of micronutrient deficiencies, the association between serum micronutrient status and osteopenia or osteoporosis, history of falls, fragility fracture, chronic musculoskeletal pain, and other long-term health risks in postmenopausal women.

The data collected were analyzed with SPSS 26.0. Quantitative variables were presented as mean ± standard deviation, and qualitative variables were presented as frequency and percentage. Exploratory analysis of categorical variables was conducted using the chi-square test, and for continuous variables, an independent sample t-test or ANOVA was used as appropriate. Correlation analysis was used to determine the correlation of serum micronutrient concentrations with BMC. Independent predictors of osteoporosis were determined using multivariable logistic regression analysis. Statistically significant difference was set at a p-value of ≤ 0.05.

Before data collection, the study received ethical approval from the appropriate institutional review board. Written informed consent was taken from all participants. All procedures were performed in compliance with ethical principles in human research, and confidentiality of personal and clinical information was respected throughout the study.

RESULTS

A total of 130 postmenopausal women were included in the study. The average age of the participants was 59.4 ± 7.1 years, and the average number of years since menopause was 9.2 ± 5.6 years. The mean body mass index was 27.8 ± 4.3 kg/m², showing that a considerable proportion of women were overweight. The most common micronutrient deficiency was vitamin D deficiency (60.0%), followed by calcium deficiency (40.0%), zinc deficiency (37.7%), and magnesium deficiency (33.8%). Bone mineral density assessment revealed that only 36 (27.7%) women had normal bone mineral density, while 55 (42.3%) had osteopenia and 39 (30.0%) osteoporosis. This means that almost 75 percent of the study population would have suffered from some degree of lowered mineral density in bones. The mean clinical and biochemical parameters are presented in Table 1.

Table 1. Baseline Characteristics and Micronutrient Status of Study Participants

Variable	Value
Total participants	130
Age, years	59.4 ± 7.1
Duration since menopause, years	9.2 ± 5.6
BMI, kg/m²	27.8 ± 4.3
Vitamin D deficiency	78 (60.0%)
Calcium insufficiency	52 (40.0%)
Magnesium deficiency	44 (33.8%)
Zinc deficiency	49 (37.7%)

Normal bone mineral density	36 (27.7%)
Osteopenia	55 (42.3%)
Osteoporosis	39 (30.0%)

There was a statistically significant relationship between micronutrient status and bone mineral density. Osteoporosis was found in 33 (42.3%) women with vitamin D deficiency and 6 (11.5%) women taking vitamin D. Likewise, there was a higher number of women who had calcium insufficiency with osteoporosis (24, 46.2%) compared to women who had calcium sufficiency (15, 19.2%). Significant associations also existed for magnesium and zinc deficiencies and decreased bone mineral density. Osteoporosis was identified in 20 (45.5%) women with magnesium deficiency and 22 (44.9%) women with zinc deficiency. In comparison, osteoporosis was observed in 19 (22.1%) women with adequate magnesium and 17 (21.0%) women with adequate zinc status. Table 2 shows that micronutrient deficiency was significantly related to poor skeletal health in postmenopausal women.

Table 2. Association of Micronutrient Status with Bone Mineral Density

Micronutrient Status	Normal BMD	Osteopenia	Osteoporosis	P-Value
Vitamin D deficient (n=78)	13 (16.7%)	32 (41.0%)	33 (42.3%)	<0.001
Vitamin D sufficient (n=52)	23 (44.2%)	23 (44.2%)	6 (11.5%)	
Calcium insufficient (n=52)	8 (15.4%)	20 (38.5%)	24 (46.2%)	0.002
Calcium adequate (n=78)	28 (35.9%)	35 (44.9%)	15 (19.2%)	
Magnesium deficient (n=44)	7 (15.9%)	17 (38.6%)	20 (45.5%)	0.006
Magnesium adequate (n=86)	29 (33.7%)	38 (44.2%)	19 (22.1%)	
Zinc deficient (n=49)	9 (18.4%)	18 (36.7%)	22 (44.9%)	0.004
Zinc adequate (n=81)	27 (33.3%)	37 (45.7%)	17 (21.0%)	

The biochemical changes were found to be sequential from normal bone mineral density to osteopenia and osteoporosis. Normal BMD women had the highest mean serum vitamin D level (31.4 ± 8.5 ng/mL), followed by women with osteopenia (25.6 ± 7.4 ng/mL) and women with osteoporosis (18.6 ± 6.7 ng/mL). This was statistically significant. Among women with osteoporosis, serum calcium, magnesium, and zinc concentrations also were significantly lower. However, alkaline phosphatase levels rose in a gradual manner with poorer bone mineral density, indicating more bone turnover in osteoporotic women. The lowest T-scores overall were seen in the osteoporosis group, further evidencing the correlation between micronutrient deficiency and weaker bones. Table 3 summarises all these biochemical and densitometric findings.

Table 3. Comparison of Biochemical Parameters According to Bone Mineral Density Status

Parameter	Normal BMD (N=36)	Osteopenia (N=55)	Osteoporosis (N=39)	P-Value
Vitamin D, ng/mL	31.4 ± 8.5	24.1 ± 7.2	18.6 ± 6.7	<0.001
Serum calcium, mg/dL	9.4 ± 0.4	8.9 ± 0.5	8.5 ± 0.6	<0.001
Magnesium, mg/dL	2.1 ± 0.3	1.9 ± 0.3	1.7 ± 0.2	0.003
Zinc, µg/dL	88.6 ± 13.4	76.9 ± 14.2	68.3 ± 12.7	<0.001
Alkaline phosphatase, IU/L	92.5 ± 21.3	116.8 ± 28.7	139.4 ± 35.6	<0.001
Lumbar spine T-score	−0.6 ± 0.3	−1.8 ± 0.4	−2.9 ± 0.5	<0.001
Femoral neck T-score	−0.7 ± 0.4	−1.7 ± 0.5	−2.7 ± 0.4	<0.001

Women with lower BMD had a higher prevalence of long-term health risks. Chronic musculoskeletal pain was reported by 71 (54.6%) participants, a history of falls by 38 (29.2%), and a fragility fracture by 21 (16.2%). Osteoporosis was the group with the most common complications, which were among women. 28 (71.8%) women with osteoporosis, 31 (56.4%) women with osteopenia, and 12 (33.3%) women with normal bone mineral density had chronic musculoskeletal pain. Likewise, a clear increase in the history of falls and fragility fractures was seen as bone health decreased. Among the 13 osteoporotic women,

13 (33.3%) women had a fragility fracture, and only 2 (5.6%) women with normal bone mineral density had a fracture history. Multiple micronutrient deficiency was also highest in the osteoporosis group, affecting 26 (66.7%) women. The results are shown in Table 4.

Table 4. Long-Term Health Risks According to Bone Mineral Density Status

Health Risk	Normal BMD (N=36)	Osteopenia (N=55)	Osteoporosis (N=39)	P-Value
Chronic musculoskeletal pain	12 (33.3%)	31 (56.4%)	28 (71.8%)	0.002
History of falls	5 (13.9%)	16 (29.1%)	17 (43.6%)	0.009
Fragility fracture	2 (5.6%)	6 (10.9%)	13 (33.3%)	0.001
Reduced physical activity	9 (25.0%)	24 (43.6%)	25 (64.1%)	0.003
Multiple micronutrient deficiency	6 (16.7%)	22 (40.0%)	26 (66.7%)	<0.001

Independent factors of osteoporosis were determined by applying multivariable logistic regression analysis. Osteoporosis was significantly correlated with vitamin D deficiency, calcium deficiency, zinc deficiency, a menopausal period of more than 10 years, low physical activity, and multiple micronutrient deficiency. Multiple micronutrient deficiency showed the strongest association with osteoporosis, with an adjusted odds ratio of 4.18. Vitamin D deficiency increased the odds of osteoporosis by 3.42 times, while calcium insufficiency increased the odds by 2.76 times. In addition, the low levels of zinc were found to be independently linked to osteoporosis. The adjusted model demonstrated an elevated OR for Mg deficiency, although it was not statistically significant. The regression analysis is shown in Table 5.

Table 5. Multivariable Logistic Regression Analysis for Predictors of Osteoporosis

Predictor	Adjusted OR	95% CI	P-Value
Vitamin D deficiency	3.42	1.48–7.91	0.004
Calcium insufficiency	2.76	1.21–6.28	0.016
Magnesium deficiency	2.14	0.94–4.89	0.071
Zinc deficiency	2.38	1.03–5.51	0.042
Duration since menopause >10 years	2.69	1.17–6.17	0.020
Low physical activity	2.93	1.25–6.86	0.013
Multiple micronutrient deficiency	4.18	1.81–9.67	<0.001

Overall, the results showed that micronutrient deficiencies were highly prevalent among postmenopausal women and were significantly associated with osteopenia, osteoporosis, and long-term health risks. The poorest bone mineral density profile and the greatest prevalence of musculoskeletal pain, falls, fragility fractures, and reduced physical activity were present in women with multiple micronutrient deficiencies.

DISCUSSION

This current study revealed a high prevalence of micronutrient deficiency and poor bone health in postmenopausal women. The most common abnormality was vitamin D deficiency, followed by calcium deficiency, zinc deficiency, and magnesium deficiency. Bone mineral density evaluation showed that osteopenia and osteoporosis were prevalent, meaning that the majority of postmenopausal women were clinically vulnerable to bone disease[2,3].

The results show the strong association between insufficient micronutrient status and low bone mineral density. Vitamin D-deficient women had a significantly greater prevalence of osteoporosis than vitamin D sufficient women[4]. This could be due to its direct involvement in calcium absorption, calcium–phosphorus balance, and bone mineralisation in the intestine. The fall in oestrogen in postmenopausal women causes a greater rate of bone loss, and vitamin D deficiency can also compound bone loss[5].

The calcium deficiency was also significantly associated with osteoporosis. Calcium needs to be adequate to maintain bone mineral content; however, if calcium is continually insufficient, calcium may be mobilized from bone, which will cause progressive bone demineralisation[6,7]. The combination of low vitamin D and calcium

deficiency seems to have a particular impact, as vitamin D deficiency lowers calcium absorption and can lead to secondary hyperparathyroidism and high bone turnover[8].

Zinc and magnesium deficiencies were also more common among women who had poor bone mineral density[9]. Magnesium helps to activate vitamin D, regulate parathyroid hormone, and form hydroxyapatite, and zinc helps osteoblast function, collagen synthesis, and the repair of bones. Though not statistically significant in the adjusted model, a higher incidence of magnesium deficiency among osteoporotic women may indicate an additional role for magnesium in poor skeletal health in conjunction with other micronutrients[10].

The study also revealed that women with osteoporosis had higher rates of long-term health complications, such as chronic musculoskeletal pain, falls, fragility fractures, and less physical activity[11]. These results underscore the clinical relevance of micronutrient deficiency and diminished bone mineral density, and that they are not just biochemical or radiological issues. Especially, fragility fractures can cause disability, dependency, long recovery times, and healthcare costs in elderly women[12].

The highest correlation with osteoporosis was found with multiple micronutrient deficiency[13]. This indicates that bone health is related to the overall sufficiency of multiple micronutrients and not to any one micronutrient alone. Thus, preventive measures should encompass a detailed nutritional evaluation, nutritional counseling, correction of deficiencies, safe exposure to the sun, and weight-bearing exercise[14].

This study has important clinical implications. Periodic testing of post-menopausal women for vitamin D deficiency, calcium deficiency, and abnormalities of other bone-related micronutrients could help identify women who are more likely to be at risk of osteoporosis and fractures[15]. Long-term morbidity can be reduced by early intervention with diet, supplementation, lifestyle change, and bone mineral density evaluation[16].

There are also some limitations to the study. Because of its cross-sectional nature, causal relationships have not been developed. Recall-based methods were used to determine dietary intake, and these are subject to reporting bias. The study was done in two centers with moderate numbers of participants, and multicenter studies with larger sample sizes are warranted to validate these results and to investigate long-term micronutrient correction effects[10-16].

CONCLUSION

These micronutrient deficiencies were very common among postmenopausal women and were significantly related to lower bone mineral density, osteopenia and osteoporosis, musculoskeletal pain, falls, and fragility fractures. Important predictors of osteoporosis were vitamin D deficiency, calcium insufficiency, zinc deficiency, duration since menopause, low physical activity, and multiple micronutrient deficiency. A thorough micronutrient assessment, early correction of micronutrient deficiencies, dietary changes, exercise, and regular bone health monitoring may help to ensure the maintenance of skeletal strength and to minimize the risk of developing chronic disease in the long term among post-menopausal women.

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Authors' Contributions: N.A. conceived and supervised the study. L.K. designed the study, collected data, analyzed results, and drafted the manuscript. N.J. assisted in recruitment and clinical assessment. R.A.Z. contributed to methodology and result interpretation. S.U. assisted in biochemical interpretation and manuscript editing. A.K. supported data collection and final manuscript preparation. All authors approved the final manuscript.

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