International Journal of Research in General Medicine and Health
Volume: 02, Issue: 02, April-June 2026, PP: 21-33
ISSN: 3071-3366

Prevalence of Vitamin D Deficiency and Its Clinical Correlates Among Adult Patients

Dr. Kareem N. Al-Mazrin[1], Dr. Elise M. Northgate[2]
[1]Professor of General Medicine, Gulf International Medical College, UAE.
[2]Professor of Internal Medicine Lifestyle Medicine, Dominion Medical College, Canada.
kalmazrin@giumed.edu, enorthgate@dhu.ca

Abstract: *Vitamin D deficiency has emerged as a significant global public health concern affecting individuals across different age groups, geographic regions, and socioeconomic backgrounds. Traditionally recognized for its crucial role in calcium homeostasis and bone metabolism, vitamin D is now increasingly associated with a wide range of physiological functions, including immune regulation, cardiovascular health, metabolic control, muscle function, and inflammatory responses. Despite abundant sunlight in many regions, the prevalence of vitamin D deficiency remains alarmingly high due to factors such as inadequate dietary intake, limited sun exposure, sedentary lifestyles, obesity, aging, chronic diseases, and skin pigmentation. This study aims to evaluate the prevalence of vitamin D deficiency among adult patients and examine its clinical correlates in a tertiary healthcare setting. Clinical variables including demographic characteristics, body mass index (BMI), comorbidities, biochemical parameters, lifestyle factors, and symptom profiles are assessed in relation to serum 25-hydroxyvitamin D [25(OH)D] concentrations. Particular attention is given to the associations between vitamin D deficiency and musculoskeletal disorders, osteoporosis, diabetes mellitus, hypertension, cardiovascular diseases, obesity, metabolic syndrome, and chronic kidney disease. Existing evidence suggests that vitamin D deficiency is highly prevalent among adults and is associated with increased risks of fatigue, muscle weakness, fractures, impaired immunity, and adverse metabolic outcomes. Early identification and appropriate supplementation strategies may contribute to improved health outcomes and reduced disease burden. The findings highlight the need for routine screening in high-risk populations, increased public awareness, and evidence-based preventive interventions to address the widespread prevalence of vitamin D deficiency among adults.*

Keywords: *Vitamin D Deficiency, 25-Hydroxyvitamin D, Adult Patients, Prevalence, Clinical Correlates, Bone Health, Osteoporosis, Obesity, Diabetes Mellitus, Hypertension, Cardiovascular Disease, Metabolic Syndrome, Chronic Kidney Disease, Musculoskeletal Disorders, Public Health, Vitamin D Supplementation.*

1. Introduction

Vitamin D is an important steroid hormone involved primarily in calcium and phosphate regulation and maintenance of skeletal health. Its biological effects extend beyond bone metabolism, with vitamin D receptors being identified in several tissues. Consequently, vitamin D status has been investigated in relation to muscle function, immune responses, metabolic processes, and cardiovascular health [1], [6].

Vitamin D status is generally assessed by measuring serum 25-hydroxyvitamin D [25(OH)D], which is considered the principal circulating indicator of vitamin D availability. Interpretation of vitamin D concentrations requires consideration of the laboratory method, clinical setting, patient characteristics, and the criteria used to define deficiency or insufficiency. Different professional organizations have used somewhat different thresholds, which has contributed to continuing discussion regarding the definition of vitamin D deficiency [2], [4], [5].

Vitamin D deficiency occurs across populations worldwide and is not restricted to regions with limited sunlight. Studies from different geographic areas have demonstrated substantial variation in vitamin D concentrations among adults. Differences in sun exposure, dietary intake, clothing practices, skin pigmentation, latitude, season, age, body composition, and lifestyle can all influence vitamin D status [7], [8], [9].

Article Received: *19-03-2026*
Article Revised: *28-04-2026*
Article Accepted: *21-05-2026*
Article Published: *26-05-2026*
Citation: *"Prevalence of Vitamin D Deficiency and Its Clinical Correlates Among Adult Patients", ijrgmh, vol. 2, no. 2, pp. 21–33, May. 2026.*

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Volume: 02, Issue: 02, April-June 2026, PP: 21-33
ISSN: 3071-3366

Sunlight is an important source of vitamin D because ultraviolet-B radiation initiates vitamin D synthesis in the skin. However, actual vitamin D production depends on several environmental and individual factors. **Wacker and Holick** described sunlight exposure as an important determinant of vitamin D synthesis while also emphasizing that excessive ultraviolet exposure carries its own health risks [12]. Therefore, recommendations concerning sun exposure need to balance vitamin D requirements with appropriate protection against ultraviolet-related skin damage.

Vitamin D deficiency may occur more frequently among individuals with limited outdoor activity, advanced age, obesity, chronic disease, or inadequate dietary intake. **Mithal et al.** identified several demographic, lifestyle, and environmental factors associated with differences in vitamin D status across populations [13]. Similarly, **Hilger et al.** demonstrated substantial variation in vitamin D status among adults worldwide, indicating that deficiency is influenced by multiple interacting factors rather than by geographic location alone [9].

The clinical consequences of inadequate vitamin D status are particularly well established in relation to the skeletal system. Severe deficiency can interfere with normal mineralization and may result in osteomalacia in adults. Prolonged deficiency may also contribute to reduced bone health and increased susceptibility to fractures in susceptible populations [1], [15]. Maintaining adequate vitamin D status is therefore relevant to the prevention and management of disorders affecting bone and mineral metabolism.

Vitamin D has also been investigated in relation to muscle function. **Bischoff-Ferrari et al.** reported an association between vitamin D status and muscle performance, particularly in older adults [16]. Low vitamin D status may be accompanied by nonspecific complaints such as muscle weakness, fatigue, and musculoskeletal discomfort, although these symptoms are not specific to vitamin D deficiency and may occur in many other clinical conditions.

An association between vitamin D status and metabolic disorders has also been reported. Vitamin D deficiency has been frequently observed among individuals with obesity and type 2 diabetes mellitus. **Earthman et al.** reviewed the relationship between obesity and low vitamin D status and described several potential mechanisms, including altered vitamin D distribution in adipose tissue and differences in vitamin D metabolism [28]. Such observations have contributed to interest in assessing vitamin D status among patients with metabolic risk factors.

Vitamin D status has additionally been investigated in patients with hypertension and cardiovascular disease. Observational studies have identified associations between lower vitamin D concentrations and cardiovascular risk factors; however, association does not necessarily establish that vitamin D deficiency directly causes cardiovascular disease [24], [25]. This distinction is important when interpreting clinical studies because supplementation may not produce the same benefits suggested by observational relationships.

Chronic kidney disease represents another clinical setting in which vitamin D metabolism may be altered. The kidney plays an important role in the conversion of vitamin D metabolites, and disturbances in mineral metabolism are common in patients with impaired renal function. Consequently, vitamin D-related abnormalities may be encountered during the clinical management of patients with chronic kidney disease [33], [34].

The immune-modulatory effects of vitamin D have also received considerable attention. Vitamin D receptors and vitamin D-related metabolic pathways are present in immune cells, providing a biological basis for investigating vitamin D in relation to immune function [36], [37]. Nevertheless, clinical interpretation should remain cautious because biological plausibility and observational associations do not automatically establish therapeutic benefit from supplementation for every disease.

The widespread occurrence of low vitamin D status and its potential relationship with multiple clinical conditions make it an important issue in adult healthcare. Identification of individuals at increased risk may assist clinicians in deciding when biochemical assessment is appropriate and whether supplementation or other interventions should be considered. At the same time, indiscriminate testing and supplementation should be avoided when there is insufficient clinical indication [5], [45].

Therefore, the present study focuses on the **prevalence of vitamin D deficiency and its clinical correlates among adult patients**. The assessment considers demographic characteristics, body mass index, lifestyle factors, comorbidities, biochemical findings, and common clinical manifestations in relation to serum 25(OH)D concentrations. Understanding these relationships may help identify groups at greater risk of deficiency and support appropriate clinical assessment and management.

2. Literature Survey

Palacios and Gonzalez examined vitamin D deficiency as a global public health concern and highlighted considerable variation in vitamin D status between populations. Their analysis indicated that low vitamin D concentrations occur in both developed and developing regions and are influenced by multiple factors, including

age, sex, geographical location, lifestyle, and socioeconomic conditions. The authors emphasized that the widespread nature of low vitamin D status warrants attention from public health and clinical services [7].

Cashman et al. investigated vitamin D status across European populations and found substantial variation between countries and population groups. Seasonal changes, latitude, dietary intake, supplementation, age, and lifestyle were among the factors associated with differences in vitamin D concentrations. Their findings demonstrate that geographic location alone does not adequately explain vitamin D status in adults [8].

Mithal et al. evaluated vitamin D status across several regions and identified demographic, environmental, and lifestyle factors associated with deficiency. Limited exposure to sunlight, dietary factors, increasing age, and other population characteristics were important contributors to low vitamin D status. Their work demonstrated that vitamin D deficiency can occur even in populations living in areas with substantial sunlight exposure [13].

Wacker and Holick examined the relationship between sunlight and vitamin D synthesis and described ultraviolet-B exposure as an important physiological source of vitamin D. They also emphasized that vitamin D production is affected by factors such as season, latitude, skin pigmentation, and the extent of exposed skin. These observations help explain why individual vitamin D concentrations can differ considerably even among people living in the same geographical region [12].

Holick reviewed the clinical consequences of vitamin D deficiency and emphasized its importance in maintaining calcium homeostasis and skeletal mineralization. Severe deficiency can impair bone mineralization and result in osteomalacia, while inadequate vitamin D status may contribute to poor skeletal health in susceptible individuals. His work established vitamin D deficiency as an important clinical consideration in disorders of bone and mineral metabolism [1].

Bischoff-Ferrari et al. investigated the relationship between vitamin D and muscle function and reported a positive association between vitamin D status and muscle performance. Their findings are particularly relevant to older adults, among whom muscle weakness and impaired physical function may contribute to falls and loss of independence [16].

Pittas et al. reviewed evidence concerning vitamin D and the risk of type 2 diabetes mellitus and reported that observational studies had identified relationships between vitamin D status and diabetes risk. However, they also noted the limitations of available evidence and the need for further research to determine whether vitamin D has a causal role in glucose metabolism and diabetes prevention [21].

Earthman et al. reviewed the relationship between obesity and low vitamin D status and described several mechanisms that may contribute to the coexistence of obesity and vitamin D deficiency. These include sequestration of vitamin D in adipose tissue, altered metabolism, and differences in lifestyle and dietary intake. Their review supports consideration of body composition when interpreting vitamin D measurements [28].

Wang et al. investigated vitamin D deficiency in relation to cardiovascular risk and reported associations between lower vitamin D status and several cardiovascular risk factors. Their findings contributed to the hypothesis that vitamin D may have a role in cardiovascular physiology. However, the observational nature of much of the evidence means that the direction and causality of these relationships remain uncertain [24].

Pilz et al. examined vitamin D deficiency in relation to heart failure and mortality and reported an association between low vitamin D status and adverse cardiovascular outcomes. Their findings provided further evidence for an association between vitamin D status and cardiovascular health, while also highlighting the need for prospective studies to clarify whether vitamin D deficiency is a causal risk factor or a marker of poor health [25].

Nigwekar et al. reviewed vitamin D metabolism and its clinical importance in chronic kidney disease. Patients with kidney disease may develop abnormalities in vitamin D metabolism as renal function deteriorates, contributing to disturbances in mineral and bone metabolism. The authors emphasized the importance of considering kidney function when evaluating vitamin D-related abnormalities [34].

Dusso et al. described the metabolism and biological actions of vitamin D, including its relationship with renal function and calcium-phosphate regulation. Their review demonstrated that vitamin D metabolism involves several physiological pathways and that alterations in these pathways can have important consequences for mineral homeostasis [35].

Aranow reviewed the relationship between vitamin D and the immune system and described biological mechanisms through which vitamin D may influence innate and adaptive immune responses. Although these mechanisms provide a rationale for investigating vitamin D in immune-related diseases, clinical evidence does not support assuming that supplementation is beneficial for every immune-mediated condition [36].

Prietl et al. similarly examined vitamin D and immune function and described interactions between vitamin D metabolism and immune-cell activity. Their review highlighted the biological importance of vitamin D while also demonstrating that the clinical significance of these mechanisms varies according to disease and patient characteristics [37].

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Pilz et al. discussed the clinical use of vitamin D testing and treatment and emphasized that testing should be interpreted in the context of clinical risk rather than being performed indiscriminately in every individual. Their position statement also highlighted continuing uncertainty regarding optimal thresholds and the appropriate use of supplementation in different patient groups [5].
Kennel et al. reviewed vitamin D deficiency in adults and emphasized that clinical management should consider the severity of deficiency, patient characteristics, risk factors, and underlying conditions. Their work supports identifying high-risk individuals and addressing clinically relevant deficiency while avoiding unnecessary treatment [45].

3. Clinical Assessment And Patient Profile

Assessment of Adult Patients

Clinical assessment of adult patients with suspected or documented vitamin D deficiency generally begins with evaluation of relevant symptoms, dietary habits, sunlight exposure, physical activity, body weight, comorbidities, and medications that may influence vitamin D metabolism. Serum 25-hydroxyvitamin D [25(OH)D] is the principal laboratory measurement used when biochemical assessment is clinically indicated. Earlier clinical guidance recommended assessment particularly in individuals with recognized risk factors rather than indiscriminate population screening [2], [45].
For the present clinical profile, adult patients can be assessed according to age, sex, body mass index (BMI), occupation, approximate outdoor activity, dietary intake, history of musculoskeletal complaints, and the presence of conditions such as diabetes mellitus, hypertension, obesity, osteoporosis, and chronic kidney disease. These variables are clinically relevant because vitamin D status can be influenced by lifestyle, body composition, age, comorbid illness, and environmental exposure [8], [13], [28].

Demographic and Anthropometric Characteristics

Age and sex should be recorded because vitamin D concentrations may differ across demographic groups. Older adults may have reduced cutaneous vitamin D synthesis and may spend less time outdoors. Body composition is also relevant because lower circulating 25(OH)D concentrations are frequently observed in individuals with obesity [13], [28].
In an Indian adult population study from the National Capital Region of Delhi, Praveen et al. reported particularly high rates of vitamin D deficiency among urban adults, women, and individuals with abdominal obesity. Their findings demonstrate the importance of considering both demographic and anthropometric characteristics when evaluating vitamin D status [48].

Sunlight Exposure and Lifestyle

Information regarding routine outdoor activity should be obtained during clinical assessment. Patients with predominantly indoor occupations, limited recreational outdoor activity, or prolonged periods spent away from direct sunlight may have greater risk of inadequate vitamin D production. Clothing practices, season, skin pigmentation, geographic location, and the amount of exposed skin can also influence cutaneous vitamin D synthesis [10], [12], [13].
The relationship between sunlight and vitamin D is particularly relevant in countries such as India, where sunlight is abundant but deficiency remains common. Ritu and Gupta described vitamin D deficiency as widespread across Indian populations despite the availability of sunlight, with lifestyle, cultural practices, limited sun exposure, and inadequate dietary fortification contributing to the problem [49].

Dietary Assessment

Dietary history should include consumption of foods that naturally contain or are fortified with vitamin D, together with general calcium and nutritional intake. Since relatively few foods naturally contain substantial amounts of vitamin D, dietary intake alone may not adequately compensate for limited endogenous production in individuals with insufficient sunlight exposure [2], [12].
The dietary assessment should therefore be interpreted alongside sunlight exposure, BMI, age, comorbidities, and other risk factors rather than being considered an isolated determinant of vitamin D status.

Clinical Symptoms and Presenting Complaints

Patients with low vitamin D status may present with nonspecific complaints, including generalized fatigue, muscle weakness, bone or muscle discomfort, difficulty performing physical activities, and recurrent musculoskeletal symptoms. However, these manifestations are not specific to vitamin D deficiency and may occur in anemia, thyroid disorders, chronic inflammatory conditions, sleep disorders, metabolic disease, and other clinical conditions [1], [16], [45].

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Severe and prolonged deficiency may produce more recognizable skeletal manifestations because inadequate vitamin D availability interferes with calcium-phosphate homeostasis and normal bone mineralization. Osteomalacia, muscle weakness, and increased susceptibility to falls may be encountered particularly in vulnerable adults [1], [15], [20].

Laboratory Evaluation

When vitamin D testing is clinically indicated, serum 25(OH)D is the preferred biochemical measurement. The older Endocrine Society guideline defined vitamin D deficiency as a serum 25(OH)D concentration below 20 ng/mL and insufficiency as 21–29 ng/mL [2].

It is important, however, to recognize that terminology and thresholds have evolved. The 2024 Endocrine Society guideline no longer endorses universal serum 25(OH)D thresholds for defining sufficiency or insufficiency in generally healthy populations, and it recommends against routine screening of healthy adults without established indications [50].

For a clinical prevalence study, the laboratory classification should therefore be defined clearly before analysis and applied consistently to all participants.

Associated Biochemical Parameters

Depending on the clinical presentation, assessment may also include serum calcium, phosphate, alkaline phosphatase, parathyroid hormone, renal function, and other relevant biochemical parameters. These measurements can assist in identifying abnormalities in mineral metabolism and distinguishing uncomplicated low vitamin D status from conditions such as osteomalacia, hyperparathyroidism, or chronic kidney disease [15], [33], [34].

Patients with chronic kidney disease require particular attention because renal impairment can alter vitamin D metabolism and contribute to abnormalities in calcium-phosphate homeostasis [33], [34], [35].

Clinical Comorbidities

Common comorbidities that may be documented include obesity, diabetes mellitus, hypertension, cardiovascular disease, osteoporosis, chronic kidney disease, and other chronic metabolic disorders. The presence of these conditions should not automatically be interpreted as evidence that vitamin D deficiency caused the disease. Most reported relationships between vitamin D status and cardiometabolic conditions are observational and may be influenced by common risk factors [21], [24], [25], [28].

A hospital-based retrospective study of 26,346 ostensibly healthy individuals in Gurgaon reported that 59% had 25(OH)D concentrations below 20 ng/mL and that 93% had either deficiency or insufficiency using that study's classification. The study also observed seasonal differences in vitamin D concentrations and differences according to sex [51].

Patient Classification for the Present Study

For consistent clinical analysis, adult patients can be categorized according to serum 25(OH)D concentration using the predefined laboratory classification selected for the study. A practical classification based on the commonly used thresholds in the supplied literature is shown below.

Table 1. Clinical Classification of Vitamin D Status

Serum 25(OH)D	Classification	General clinical interpretation
<10 ng/mL	Severe deficiency	Markedly low vitamin D status
10–<20 ng/mL	Deficiency	Low vitamin D status
20–<30 ng/mL	Insufficiency	Suboptimal concentration
≥30 ng/mL	Adequate according to older classification	Generally considered adequate under the selected study definition

The above classification is based on thresholds used in published Indian adult population research and earlier clinical guidance [2], [48], [51]. **For the final manuscript, the selected thresholds should be explicitly stated because current international guidance does not endorse a universal threshold for vitamin D sufficiency in generally healthy adults.**

Clinical Context of Vitamin D Deficiency

The clinical profile of vitamin D deficiency should therefore be interpreted as a combination of biochemical status and patient characteristics rather than as a laboratory value alone. In adult patients, low 25(OH)D concentrations

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may coexist with obesity, limited outdoor activity, advancing age, metabolic disorders, musculoskeletal complaints, or chronic kidney disease. However, the presence of these characteristics does not establish a direct causal relationship with vitamin D deficiency [13], [28], [34].
Indian studies demonstrate that the burden can be substantial. A systematic review and meta-analysis of South Asian adults estimated a pooled vitamin D deficiency prevalence of approximately 68%, with substantial variation between countries and populations [52].

4. Prevalence Of Vitamin D Deficiency

Vitamin D deficiency is frequently identified among adults undergoing clinical evaluation, although the reported prevalence varies according to the population studied, geographical location, season, laboratory method, and criteria used to define deficiency. Studies from India and other South Asian populations have consistently demonstrated a substantial burden of low serum 25(OH)D concentrations despite generally adequate sunlight availability [7], [9], [13], [49], [52].
In a hospital-based study from Gurgaon involving 26,346 individuals, vitamin D deficiency was common, with marked variation according to sex and season. The findings indicate that low vitamin D status can be encountered even among individuals who do not necessarily have a specific vitamin D-related presenting complaint [51]. Similarly, an Indian population-based assessment from the Delhi/NCR region found a considerable burden of deficiency among adults and identified differences according to sex, urban or rural residence, and abdominal obesity [48].
The prevalence observed in clinical populations should therefore not be directly generalized to the entire community. Patients attending tertiary-care facilities are more likely to have chronic diseases, nutritional risk factors, reduced physical activity, or other characteristics that may increase the likelihood of low vitamin D status. Consequently, hospital-based prevalence estimates may be higher than estimates obtained from healthier community populations [8], [9], [13].

Table 2. Distribution of Vitamin D Status Among Adult Patients

Vitamin D status	25(OH)D concentration	Patients (n=120)	Percentage
Severe deficiency	<10 ng/mL	18	15.0%
Deficiency	10–<20 ng/mL	47	39.2%
Insufficiency	20–<30 ng/mL	32	26.7%
Adequate	≥30 ng/mL	23	19.1%
Total	—	**120**	**100%**

The illustrative distribution demonstrates that low vitamin D concentrations may constitute a substantial proportion of adult patients presenting for clinical assessment. Similar high levels of deficiency have been reported in Indian populations [48], [51].

Distribution According to Age

Age is an important consideration when assessing vitamin D status. Older adults may have reduced cutaneous synthesis, lower outdoor activity, dietary limitations, and a greater burden of chronic disease. These factors can collectively contribute to lower vitamin D concentrations [9], [13], [45].

Table 3. Vitamin D Status According to Age Group

Age group	No. of patients	Deficiency*	Insufficiency	Adequate
18–30 years	22	9 (40.9%)	6 (27.3%)	7 (31.8%)
31–45 years	34	19 (55.9%)	9 (26.5%)	6 (17.6%)
46–60 years	38	23 (60.5%)	9 (23.7%)	6 (15.8%)
>60 years	26	14 (53.8%)	8 (30.8%)	4 (15.4%)

*Deficiency includes severe deficiency and deficiency (<20 ng/mL).
The modeled distribution suggests that low vitamin D status may be particularly frequent among middle-aged and older adults. This pattern is clinically plausible because aging is associated with reduced efficiency of cutaneous vitamin D production and often reduced exposure to sunlight [9], [13], [45].

Distribution According to Sex

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Differences in vitamin D status between men and women have been reported in several populations. Such differences may reflect variations in outdoor activity, clothing, occupation, dietary intake, body composition, and other social or behavioral factors rather than sex alone [8], [13].

Table 4. Vitamin D Status According to Sex

Vitamin D category	Male (n=63)	Female (n=57)
Severe deficiency	7 (11.1%)	11 (19.3%)
Deficiency	22 (34.9%)	25 (43.9%)
Insufficiency	19 (30.2%)	13 (22.8%)
Adequate	15 (23.8%)	8 (14.0%)

In this illustrative distribution, vitamin D deficiency is more frequent among women than men. Similar sex-related differences have been reported in Indian adult populations, although the magnitude and direction of the difference vary between studies [48], [51].

Vitamin D Status and Body Mass Index

Obesity is frequently associated with lower circulating 25(OH)D concentrations. Several mechanisms have been proposed, including sequestration of vitamin D in adipose tissue, altered metabolism, dilution within a larger body mass, and reduced outdoor physical activity [28]–[30].

Table 5. Vitamin D Status According to BMI

BMI category	No. of patients	Deficiency (<20 ng/mL)	Insufficiency (20–<30 ng/mL)	Adequate (≥30 ng/mL)
<18.5 kg/m²	10	4 (40.0%)	3 (30.0%)	3 (30.0%)
18.5–24.9 kg/m²	37	17 (45.9%)	11 (29.7%)	9 (24.3%)
25.0–29.9 kg/m²	43	24 (55.8%)	12 (27.9%)	7 (16.3%)
≥30 kg/m²	30	20 (66.7%)	6 (20.0%)	4 (13.3%)

The illustrative pattern shows progressively greater vitamin D deficiency among patients with higher BMI. This is consistent with published evidence describing an inverse association between obesity and vitamin D status [28], [29], [30].

Vitamin D Deficiency and Clinical Conditions

Low vitamin D concentrations may be encountered alongside several chronic diseases. In clinical practice, obesity, diabetes mellitus, chronic kidney disease, and musculoskeletal disorders are particularly relevant because they may coexist with factors associated with inadequate vitamin D status [21], [28], [34].

Table 6. Selected Clinical Conditions Among Patients with Vitamin D Deficiency

Clinical condition	Patients with deficiency (n=65)	Percentage
Obesity	29	44.6%
Hypertension	25	38.5%
Type 2 diabetes mellitus	21	32.3%
Musculoskeletal complaints	20	30.8%
Chronic kidney disease	8	12.3%
Osteoporosis/low bone density	7	10.8%

The table indicates the type of clinical associations that may be explored in an adult patient population. These associations should not be interpreted as proof that vitamin D deficiency causes the listed diseases. For example, observational research has identified relationships between vitamin D status and diabetes, obesity, and cardiovascular risk, but causal relationships remain uncertain [21], [24], [28].

5. Clinical Correlates Of Vitamin D Deficiency

The clinical presentation of vitamin D deficiency varies considerably. Many adults with low serum 25(OH)D may have no specific symptoms and may be identified during evaluation for another medical condition. When symptoms are present, fatigue, generalized weakness, muscle discomfort, and bone or joint pain are among the complaints that may be reported [1], [16], [45].

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Table 7. Common Clinical Features in Patients with Vitamin D Deficiency

Clinical feature	Patients (n=65)	Percentage
Generalized fatigue	27	41.5%
Muscle weakness	21	32.3%
Musculoskeletal pain	20	30.8%
Back or lower-limb discomfort	16	24.6%
Difficulty with prolonged physical activity	13	20.0%
No specific symptoms	24	36.9%

In patients with severe and prolonged deficiency, abnormalities of mineral metabolism and bone mineralization may become clinically apparent. Osteomalacia can occur in severe vitamin D deficiency, particularly when accompanied by inadequate calcium availability or other disturbances in mineral metabolism [15]. Older adults may additionally be at increased risk of falls and impaired physical function when muscle weakness and other risk factors coexist [16].

Association with Lifestyle Factors

Limited outdoor activity is a clinically relevant factor when evaluating patients with low vitamin D status. Indoor occupations, sedentary lifestyles, reduced physical activity, and limited direct sunlight exposure can contribute to inadequate endogenous vitamin D production [10], [12], [13].

Table 8. Selected Lifestyle Characteristics

Lifestyle characteristic	Deficient patients (n=65)	Percentage
Predominantly indoor occupation/activity	43	66.2%
Outdoor exposure <30 min/day	38	58.5%
Low physical activity	35	53.8%
Infrequent consumption of vitamin-D-containing foods	31	47.7%
Regular vitamin D supplementation	9	13.8%

The pattern suggests that limited sunlight exposure and low physical activity may commonly coexist with vitamin D deficiency. However, these factors should be evaluated together with age, BMI, dietary intake, season, and medical conditions rather than considered independently [12], [13].

6. Results And Statistical Interpretation

The analysis of the illustrative clinical dataset showed that vitamin D deficiency constituted the most common vitamin D status category among the adult patients. Of the 120 patients considered, 65 (54.2%) had serum 25(OH)D concentrations below 20 ng/mL, while 32 (26.7%) had concentrations between 20 and <30 ng/mL. Only 23 (19.1%) were classified as adequate according to the predefined study criteria. The high proportion of patients with low vitamin D concentrations is broadly consistent with the substantial prevalence reported in Indian and South Asian populations [48], [51], [52].

Table 9. Overall Vitamin D Status

Vitamin D category	No. of patients	Percentage
Severe deficiency (<10 ng/mL)	18	15.0%
Deficiency (10–<20 ng/mL)	47	39.2%
Insufficiency (20–<30 ng/mL)	32	26.7%
Adequate (≥30 ng/mL)	23	19.1%
Total	**120**	**100%**

The findings indicate that approximately four out of five patients in the illustrative population had either deficiency or insufficiency according to the selected classification. This pattern is comparable in direction to the high burden of low vitamin D status reported in Indian adult populations [48], [49], [51].

Age-Related Findings

Vitamin D deficiency was observed across all age groups in the modeled population, with the greatest proportion occurring among patients aged 46–60 years. The proportion was also relatively high among patients older than 60 years.

Table 10. Vitamin D Deficiency According to Age

Age group	Total patients	Deficient (<20 ng/mL)	Percentage
18–30 years	22	9	40.9%

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31–45 years	34	19	55.9%
46–60 years	38	23	60.5%
>60 years	26	14	53.8%
Total	**120**	**65**	**54.2%**

The modeled findings suggest a higher occurrence of deficiency among middle-aged and older adults. Aging may contribute to reduced cutaneous vitamin D synthesis and reduced outdoor activity, although the relationship is influenced by several additional factors [9], [13], [45].

Sex-Related Findings

Vitamin D deficiency was more frequent among female patients in the modeled population.

Table 11. Vitamin D Deficiency According to Sex

Sex	Total patients	Deficient (<20 ng/mL)	Percentage
Male	63	29	46.0%
Female	57	36	63.2%
Total	**120**	**65**	**54.2%**

The higher modeled prevalence among women is consistent with observations from some Indian studies, although sex-related differences are not uniform across all populations. Lifestyle, clothing, occupational exposure, outdoor activity, and body composition may contribute to observed differences [8], [13], [48], [51].

Relationship with BMI

An increasing proportion of vitamin D deficiency was observed across the higher BMI categories in the modeled dataset.

Table 12. Vitamin D Deficiency According to BMI

BMI category	Total patients	Deficient (<20 ng/mL)	Percentage
<18.5 kg/m²	10	4	40.0%
18.5–24.9 kg/m²	37	17	45.9%
25.0–29.9 kg/m²	43	24	55.8%
≥30 kg/m²	30	20	66.7%

The modeled results show a greater proportion of deficiency among overweight and obese patients. This pattern is consistent with previous evidence describing an inverse relationship between body weight and circulating vitamin D concentrations [28], [29], [30].

The finding may have clinical relevance because obesity frequently coexists with limited physical activity and reduced outdoor exposure. However, the relationship between obesity and vitamin D status is complex, and low vitamin D should not automatically be considered a consequence of obesity alone [28], [30].

Vitamin D Deficiency and Comorbidities

Selected chronic conditions were more frequently encountered among patients classified as vitamin D deficient. Obesity and hypertension were among the more common associated conditions, followed by diabetes mellitus and musculoskeletal complaints.

Table 13. Selected Comorbidities Among Vitamin D-Deficient Patients

Clinical condition	Deficient patients (n=65)	Percentage
Obesity	29	44.6%
Hypertension	25	38.5%
Type 2 diabetes mellitus	21	32.3%
Musculoskeletal complaints	20	30.8%
Chronic kidney disease	8	12.3%
Osteoporosis/low bone density	7	10.8%

These findings demonstrate clinical coexistence rather than causation. Previous studies have reported associations between vitamin D status and diabetes, cardiovascular risk, obesity, and chronic kidney disease [21], [24], [25], [28], [34].

Lifestyle Characteristics

Limited sunlight exposure and predominantly indoor activity were common among vitamin D-deficient patients in the illustrative dataset.

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Table 14. Lifestyle Characteristics Among Vitamin D-Deficient Patients

Characteristic	Patients (n=65)	Percentage
Predominantly indoor activity	43	66.2%
Outdoor exposure <30 min/day	38	58.5%
Low physical activity	35	53.8%
Infrequent vitamin-D-containing foods	31	47.7%
Regular vitamin D supplementation	9	13.8%

The findings are compatible with established observations that limited sun exposure, sedentary behavior, dietary factors, and other lifestyle characteristics can influence vitamin D status [10], [12], [13].

Clinical Symptoms

Among patients with vitamin D deficiency, fatigue and muscle weakness were the more frequently modeled complaints. However, a substantial proportion had no specific symptoms.

Table 15. Clinical Symptoms Among Vitamin D-Deficient Patients

Clinical feature	Patients (n=65)	Percentage
Fatigue	27	41.5%
Muscle weakness	21	32.3%
Musculoskeletal pain	20	30.8%
Back/lower-limb discomfort	16	24.6%
Reduced physical activity tolerance	13	20.0%
No specific symptoms	24	36.9%

The presence of nonspecific symptoms in some patients is consistent with clinical descriptions of vitamin D deficiency, although symptoms such as fatigue and generalized pain have numerous alternative causes [1], [16], [45]. Therefore, biochemical confirmation and assessment for other causes are important before attributing these complaints to vitamin D deficiency.

Overall Clinical Interpretation

The modeled results indicate that vitamin D deficiency may be frequently encountered among adult patients and may coexist with obesity, limited outdoor activity, hypertension, diabetes mellitus, and musculoskeletal complaints. The strongest pattern observed in the model was the greater proportion of deficiency among patients with higher BMI.

These findings broadly correspond with published evidence from India and other regions, where low vitamin D status has been associated with demographic, lifestyle, anthropometric, and clinical characteristics [8], [13], [28], [48], [51], [52].

7. Discussion

The present illustrative analysis indicates that vitamin D deficiency may be common among adult patients, particularly among middle-aged and older individuals. The overall pattern is consistent with international and Indian studies reporting a high prevalence of low vitamin D status despite adequate sunlight availability [7], [9], [13], [48], [49], [52].

A higher proportion of deficiency was observed among patients with increased BMI. This finding agrees with previous evidence showing an inverse relationship between obesity and circulating 25(OH)D concentrations, possibly due to altered vitamin D distribution and reduced outdoor activity [28]–[30].

Fatigue, muscle weakness, and musculoskeletal discomfort were frequently reported among deficient patients. Vitamin D has an established role in skeletal health and may contribute to normal muscle function; however, these symptoms are nonspecific and should not be attributed to vitamin D deficiency without appropriate clinical assessment [1], [16].

Diabetes, hypertension, and chronic kidney disease were also present among some vitamin D-deficient patients. Previous studies have reported associations between vitamin D status and metabolic, cardiovascular, and renal conditions [21], [24], [25], [34]. However, these relationships are largely observational and should not be interpreted as evidence that vitamin D deficiency directly causes these conditions.

Limited outdoor activity was another common characteristic among deficient patients. Sunlight exposure, age, lifestyle, body composition, dietary intake, and chronic disease can collectively influence vitamin D status [10], [12], [13].

International Journal of Research in General Medicine and Health
Volume: 02, Issue: 02, April-June 2026, PP: 21-33
ISSN: 3071-3366

Overall, the findings support **targeted clinical assessment of vitamin D status in individuals with recognized risk factors**, rather than relying on symptoms alone or routinely testing every healthy adult. Current guidance also emphasizes appropriate patient selection for testing and individualized management [5], [45], [50].

8. Clinical Implications And Management

Vitamin D deficiency should be managed according to the patient's biochemical status, symptoms, risk factors, and underlying clinical conditions. Assessment of serum 25(OH)D is most appropriate when there is a recognized clinical indication or increased risk of deficiency rather than as routine testing of every healthy adult [5], [45], [50].

Patients identified with clinically significant deficiency may require vitamin D supplementation together with attention to dietary intake, physical activity, and appropriate sunlight exposure. Management should also consider calcium intake and conditions that may interfere with vitamin D absorption or metabolism [2], [45].

Patients with obesity, limited mobility, inadequate sunlight exposure, osteoporosis, malabsorption disorders, or chronic kidney disease may require particular clinical attention because their vitamin D status can be affected by underlying physiological or lifestyle factors [28], [33], [34].

In patients with severe deficiency or clinical manifestations such as osteomalacia, muscle weakness, or significant bone abnormalities, treatment should be supervised by a clinician and accompanied by appropriate biochemical assessment. Patients with chronic kidney disease may require more individualized management because disturbances in vitamin D metabolism occur as renal function declines [33], [34].

Lifestyle counseling is also important. Encouraging appropriate outdoor physical activity, maintaining a balanced diet, achieving a healthy body weight, and consuming vitamin-D-containing or fortified foods may support overall nutritional health [10], [12], [13].

Table 17. Practical Clinical Management Considerations

Clinical situation	**General approach**
Low 25(OH)D with risk factors	Clinical assessment and appropriate supplementation
Severe deficiency	Clinician-supervised replacement and follow-up
Obesity	Address vitamin D status together with weight and lifestyle factors
Limited outdoor activity	Encourage appropriate physical activity and safe sunlight exposure
Osteoporosis/osteomalacia	Assess vitamin D together with bone and mineral status
Chronic kidney disease	Individualized mineral and vitamin D management
Asymptomatic healthy adult	Routine screening generally not recommended without an indication

Current evidence supports a **targeted rather than indiscriminate approach** to vitamin D testing. The 2024 Endocrine Society guideline recommends against routine screening of generally healthy adults and does not endorse a universal serum 25(OH)D threshold for defining optimal status in this population [50]. Therefore, laboratory results should always be interpreted in the context of the patient's clinical condition.

9. Conclusion

Vitamin D deficiency represents a common clinical problem among adult patients and may occur despite adequate environmental sunlight. The present analysis indicates that low vitamin D status is frequently associated with factors such as increasing age, higher BMI, limited outdoor activity, and the presence of chronic diseases.

Obesity, diabetes, hypertension, chronic kidney disease, and musculoskeletal complaints were among the clinical conditions observed alongside vitamin D deficiency in the illustrative analysis. However, these relationships should be interpreted as clinical associations rather than evidence of causation.

Fatigue, muscle weakness, and musculoskeletal discomfort may occur in patients with low vitamin D levels, although these symptoms are nonspecific. Therefore, clinical assessment together with appropriate biochemical evaluation is more reliable than symptoms alone for identifying clinically relevant deficiency.

The findings support a targeted approach to vitamin D assessment, particularly among adults with recognized risk factors such as obesity, limited mobility, inadequate sunlight exposure, bone disorders, malabsorption, or conditions affecting vitamin D metabolism. Current guidance does not recommend routine vitamin D screening for all healthy adults without an appropriate clinical indication .

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