Vitamin D in Office Workers: A Review of Musculoskeletal and Immune System Optimization for Enhanced Productivity

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ABSTRACT

Vitamin D deficiency is a significant health issue, particularly among office workers. This literature review emphasizes the availability of evidence on vitamin D deficiency and its impacts on musculoskeletal health and immune functions, especially amongst office workers. A literature search of PubMed, Scopus, and Web of Science identified relevant studies on the relationship between vitamin D status and musculoskeletal health and infection risks, highlighting the prevalence of vitamin D deficiency in office workers due to limited sunlight exposure and sedentary lifestyles. The risks of osteoporosis, muscle weakness, and musculoskeletal pain, as well as impaired immune system function, are carefully examined. Potential intervention strategies include implementing work schedules allowing for outdoor breaks, providing access to vitamin D-fortified foods or supplements, and routine screening for vitamin D levels. Addressing the low level of vitamin D in office workers is essential for promoting musculoskeletal health, supporting immune functions, and enhancing workforce productivity. This review underscores the need for further research and the implementation of evidence-based interventions to mitigate the impact of vitamin D deficiency in this population.

***Keywords**: Vitamin D deficiency, office workers, musculoskeletal, immunity.*

INTRODUCTION

Vitamin D deficiency has become a significant global health concern due to its widespread occurrence and potential effects on various health outcomes. Recent studies, especially those conducted in the aftermath of the COVID-19 pandemic, have highlighted vitamin D as a critical area of research due to its association with COVID-19 infections.[1–3] Recent surveys conducted in 2023 indicated that vitamin D deficiency has emerged as a "silent pandemic" with global prevalence rates of hypovitaminosis significantly varying from 15% to 76.6%.[4] This extensive range highlights the necessity for regionally specific evaluation and focused intervention strategies. These findings also demonstrate that vitamin D status is not only a personal concern but also a serious public health issue affecting healthcare systems and workers' productivity.

Tropical countries receive abundant sunlight, which is beneficial for vitamin D status for workers in general; however, this cannot be guaranteed. Office workers spend most of their

workdays indoors, often from morning until late in the afternoon, with limited opportunities for sun exposure during breaks; additionally, inadequate dietary intake of vitamin D exacerbates this issue further. A global systematic review of 71 studies further confirmed that indoor and shift workers consistently show lower serum 25(OH) D levels than outdoor workers, highlighting occupational sun exposure as a critical determinant.[5] Despite residing in tropical regions with abundant sunlight, workers in Southeast Asian countries remain vulnerable to vitamin D deficiency. A study in Singapore involving 213 participants found a 32.9% prevalence of vitamin D deficiency, with significantly higher risks among office, workshop, and night shift workers.[6] Similarly, among 168 Bangladeshi garment workers - predominantly young women working long indoor hours - 32% were vitamin D deficient.[7] A recent meta-analysis examining the prevalence of vitamin D deficiency in young adults in Indonesia in 2023 also revealed a concerning rate of 33.3% with significant implications for work performance and overall health.[8] This is particularly concerning given that young adults represent a critical segment of the workforce, serving as the backbone of economic productivity in various countries. Addressing vitamin D deficiency in this population is therefore not only a matter of individual health but also a key factor in maintaining economic stability.

This review aims to thoroughly summarize recent evidence regarding the effects of vitamin D deficiency on musculoskeletal health and its impact on immune function in office workers. Providing explicit insights into the clinical and strategic implications associated with managing vitamin D deficiency in the working-age population can enhance public health programs aimed at more effectively mitigating the detrimental effects of vitamin D deficiency on this economically significant demographic.

METHODOLOGY

A search was done on several large academic databases, including PubMed, Scopus, and Web of Science, for this study. The search strategy was designed to identify relevant studies examining the relationship between vitamin D deficiency and musculoskeletal health and immune system function in office workers. The following search terms were used with appropriate adaptations for each database to account for variations in indexing and search syntax: (worker* OR employee*) AND ("vitamin D deficiency" OR "vitamin D insufficiency") OR ("vitamin D loss" OR "loss of vitamin D") OR ("hypovitaminosis D" OR "25-hydroxyvitamin D") AND (musculoskeletal OR “muscle health”) OR (“bone health” OR “joint pain”) OR (“back pain” OR “osteo*”) OR (arthralgia OR myalgia) AND (“immune system” OR immunity) OR (“immune function” OR “immune response”) OR (“infection risk” OR inflammation) AND (productivity OR absenteeism) OR (presenteeism OR “work performance”).

This search string combined terms related to the study population (office workers, employees) with terms describing vitamin D deficiency and its various synonyms, as well as the concept of musculoskeletal involvement and, crucially, terms related to immune system function and employee productivity. The asterisk (*) was used as a truncation symbol to capture variations of the term "worker" (e.g., worker, workers). The selection criteria focused on peer-reviewed studies examining not only the relationship between vitamin D levels and musculoskeletal disorder outcomes in office workers but also the relationship between vitamin D levels and infection risk in office workers.

Included studies spanned observational designs, such as cross-sectional and cohort studies, as well as interventional trials where applicable. Studies were screened based on predefined parameters to ensure relevance and quality, including population characteristics, assessment methods for vitamin D status, and reported musculoskeletal and immune health outcomes and measures of productivity or work performance. The information gathered from these sources was then synthesized to provide a comprehensive overview of the current findings, identify research gaps, and propose directions for future studies.

Prevalence and Risk Factors for Vitamin D Deficiency in Office Workers

The high prevalence of vitamin D deficiency indicates a growing global health concern affecting individuals across various populations and geographical locations. A population-based study analysing global vitamin D data from 2000 to 2022 included 7.9 million participants. The study showed the serum 25-hydroxyvitamin D levels were below 30 nmol/L in 15.7% of persons, below 50 nmol/L in 47.9%, and below 75 nmol/L in 76.6% participants.[4] Similar findings have been observed in Asia, where the prevalence of vitamin D deficiency has been reported to reach 68% (95% CI: 64 to 72%). The most common rates of vitamin D deficiency in Asia were recorded in Pakistan (73%), followed by Bangladesh and India (67%), Nepal (57%), and Sri Lanka (48%).[9] Another study in the Asian population showed approximately 75% had suboptimal 25(OH)D concentration.[10] Although there is considerable controversy surrounding this study due to its data being based on countries with highly diverse populations, the findings suggest that vitamin D deficiency remains a significant concern.

Given the alarming trends, a focused examination of vitamin D deficiency prevalence within specific occupational cohorts, such as office workers, is warranted. The sedentary nature of office work, coupled with prolonged periods spent indoors under artificial lighting and limited sun exposure, predisposes this population to an elevated risk of vitamin D deficiency; consequently, sunlight exposure during working hours is insufficient for them.[11] A systematic review demonstrated that low vitamin D levels were significantly more common in indoor workers (78%) than in outdoor workers (48%).[12] Factors contributing to the increased risk of hypovitaminosis D in office workers include limited exposure to sunlight, dietary deficiencies and a sedentary lifestyle. [13] Most vitamin D (90%) is synthesized in the skin through exposure to ultraviolet B (UV-B) radiation from sunlight, while only 10% is obtained from dietary sources, such as fish, egg yolks, fortified milk, and vitamin D supplements.[14] Consequently, individuals spending most of their time indoors are less likely to receive adequate UV-B exposure for sufficient vitamin D synthesis. A more recent study of 5409 workers revealed an 88.1% vitamin D deficiency prevalence in office workers compared with 79% in factory workers, demonstrating office workers are more susceptible to vitamin D deficiency. [15]

In addition to working indoors, shift work, particularly night shifts, has also been associated with an increased risk of vitamin D deficiency. A meta-analysis of 13 cross-sectional studies involving 110,287 subjects investigated the impact of shift work as a determinant of vitamin D deficiency in industrialized countries.[16] The study revealed that shift workers had significantly lower serum 25-OH-vitamin D levels than non-shift workers. This finding may be due to reduced sun exposure among shift workers who spend most of their time working during nighttime hours and sleeping during daylight hours; however, this study is controversial since shift workers often exhibit not only vitamin D deficiency but distinct lifestyle compared to non-shift workers.

Other identified risk factors include sex (female), ethnicity, age, and body mass index (BMI). Studies conducted in Asian populations have indicated that women tend to have a higher prevalence of hypovitaminosis D compared to men.[11,17] This may be attributed to cultural practices, such as avoiding sun exposure, using sunscreen, and wearing concealing clothing. Age and season have also been found to influence vitamin D status, with younger individuals and those living in colder climates at higher risk of hypovitaminosis D. While one study suggests an association, another study reports that BMI is not significantly related to hypovitaminosis D.

A systematic evaluation of 90 cross-sectional studies demonstrated a substantial correlation between indoor work conditions, shift employment, and the prevalence of vitamin D deficiency. [11,13,18] The study found that certain professions, especially those characterized by rotational shift schedules and indoor environments (e.g., nurses, office staff, and certain factory workers), are at an elevated risk of experiencing vitamin D deficiencies. These findings suggest the need for further research into the potential benefits of targeted

nutritional education and planned sunlight exposure interventions aimed at mitigating vitamin D deficiency among indoor workers.

Impacts of Vitamin D Deficiency on Musculoskeletal Health

Vitamin D is crucial for the metabolism of calcium and phosphorus, which are both essential for maintaining healthy bones and muscles. It has long been established that vitamin D deficiency can lead to muscle fatigue, bone pain, and an increased risk of fractures.[13,14,19] These musculoskeletal manifestations can significantly impair physical function, reduce mobility, and diminish overall quality of life. The chronic nature of these symptoms can also contribute to psychological distress, further impacting an individual's ability to perform daily tasks and maintain a productive lifestyle.[20] Therefore, it is important to understand the mechanisms by which vitamin D affects musculoskeletal health to develop effective strategies to prevent and manage these debilitating conditions.

Hypovitaminosis D has long been recognized as a significant determinant of musculoskeletal health. Insufficient vitamin D levels can trigger a cascade of effects, including reduced bone mineral density, increased risk of osteoporosis, rickets, osteomalacia, and the manifestation of musculoskeletal pain.[21] Consequently, maintaining adequate vitamin D status is essential for overall musculoskeletal health.

The impact of vitamin D deficiency on bone health and osteoporosis prevention has been extensively reviewed in the literature. A bibliometric analysis tracking trends in publications related to vitamin D and bone metabolism from 2001 to 2020 identified 16,887 relevant articles extracted from the Web of Science (WoS) database, employing "R-Bibliometrix" for comprehensive analysis.[22] The study highlights the prominence of research on vitamin D and its associations with musculoskeletal outcomes in journals such as Osteoporosis International, Journal of Bone and Mineral Research, and Bone. These findings further corroborate reports of a high prevalence of osteoporosis within the population. This highlights the importance of adequate vitamin D status - whether achieved through sunlight exposure or supplementation - as a critical factor in bone health, despite ongoing debate regarding the exact mechanisms or causality in some studies.

Besides affecting bone health, vitamin D has also been linked to changes in muscle function and pain perception. Numerous studies have examined the function of vitamin D in mitigating the risk of muscle pain. A systematic review of 437 articles, culminating in a final analysis of 7 studies involving 2420 patients, demonstrated significantly lower serum vitamin D concentrations in patients experiencing muscle pain compared to those without (28.4±13.80ng/mL vs. 34.86±11.63ng/mL).[23] These findings suggest that muscle pain is significantly associated with vitamin D deficiency.

A large-scale study encompassing 25,871 participants followed for 5.3 years, identified 1551 incident fractures among 1991 individuals; however, supplemental vitamin D3 demonstrated no statistically significant effect compared to placebo in preventing total fractures or hip fractures (HR 1.01, 95% CI 0.70-1.47, P = 0.96), suggesting that supplementation does not impact fracture risks in certain populations, such as those defined by specific race, age or clinical characteristics.[24] In the meta-analysis performed by Wu et al,[25] analysing 19 randomized controlled trials involving 3,436 participants (1780 with vitamin D supplementation and 1656 with placebo), revealed a statistically significant reduction in pain scores among participants receiving vitamin D compared to the placebo group (p = 0.007). Furthermore, among the four trials reporting pain improvement, individuals receiving vitamin D supplementation exhibited a significantly greater likelihood of experiencing pain reduction compared to those receiving placebo (relative risk 1.38, 95% CI: 0.93-2.05, P = 0.11).

Impacts of Vitamin D Deficiency on Immunity in Workers and Implications for Productivity

Beyond its well-known effects on bone and muscle health, vitamin D also exerts a significant influence on the immune system. It is associated with improved immune function and a reduced risk of infections. Recent meta-analyses have demonstrated vitamin D's protective effects against upper respiratory tract infections and

its ability to modulate the immune system in response to other infections.[26,27] Consequently, workers deficient in vitamin D may experience a range of nonspecific symptoms, such as a higher incidence of infections, which can contribute to increased absenteeism and decreased work productivity.[28] These factors demonstrate that vitamin D deficiency can have implications beyond individual health, potentially affecting workforce efficiency, absenteeism rates, and overall productivity.

A widely discussed intervention is vitamin D and calcium administration, which provides essential minerals for musculoskeletal health and immune function support in office workers. This combination is expected not only to prevent musculoskeletal disorders but also to reduce the risk of getting an infection in the workplace.[26] Despite evidence suggesting vitamin D can improve musculoskeletal conditions, its overall effectiveness remains highly debated due to the complexity of associated parameters; thus, ongoing research in this area continues.

The relationship between vitamin D and infection, particularly respiratory infections, has garnered significant attention. A bibliometric analysis in 2022 highlighted the growing trend of publications on this topic, with the number of articles increasing substantially after 2012.[29] This surge in research reflects a growing recognition of vitamin D's multifaceted role in modulating immune responses, extending beyond its traditional association with bone health.

Emerging evidence reveals that vitamin D influences various immune pathways, ultimately enhancing mucosal immunity and simultaneously mitigating inflammation. Its effects on infection are mediated through alterations in immune responses via several mechanisms, such as the modulation of gene expression related to antioxidants, cytokines, and cellular metabolism and function. Vitamin D also induces genes encoding antimicrobial peptides, which possess bactericidal activity against various bacteria and viruses, including influenza and tuberculosis. Specifically, human macrophages rely on the vitamin D/LL-37 axis to combat mycobacteria, an effect mediated by the LL-37 gene via RNA interference.[30]

Vitamin D deficiency can compromise overall immune function, rendering workers more susceptible to infections, thus negatively affecting their health and attendance, leading to decreased productivity. A meta-analysis of 11 randomized controlled trials, encompassing 5660 subjects, revealed that vitamin D exhibits a protective effect against acute respiratory tract infections.[26] Therefore, maximizing vitamin D levels may potentially reduce morbidity rates, ultimately enhancing worker productivity. Given the widespread implications of vitamin D deficiency, policymakers and employers should adopt strategies to support workers in maintaining healthy vitamin D levels, considering not only bone health but also the broader implications for immune function, worker productivity, and mental well-being.

The summary of the results for the prevalence of vitamin D deficiency in workers and the impacts on musculoskeletal and immunity can be found in **Table 1**.

Systemic Strategies for Overcoming Vitamin D Deficiencies Among Indoor Workers

To mitigate the burden of vitamin D deficiency in office settings, several interventions should be considered. These include implementing work schedules that allow for outdoor breaks (e.g., during morning mini-breaks or lunch breaks for 10–15 minutes sunlight exposure during peak UVB periods),[31] providing access to vitamin D-fortified foods or supplements, encouraging weight reduction for obese workers and delivering education and campaigns on the importance of vitamin D. Designing workspaces or lunch areas that allow sunlight to enter through windows can also increase sun exposure. Shift work arrangements are also necessary so that workers can still have an opportunity to be exposed to sunlight. If possible, routine screening for vitamin D levels in workers, particularly those engaged in indoor or shift work, can also help to identify individuals requiring further intervention.[16] However, if vitamin D level screening is not feasible, the presence of symptoms related to vitamin D deficiency should also be considered when providing supplementation. Ultimately, supplementation should be prioritized for workers diagnosed with

Table 1. Summary of the Previous Study about Vitamin D in Workers

Study	Methods	Results
Divakar U, et al., 2020[6]	A cross-sectional study, 213 participants (aged ≥ 21 years) from four workplaces in Singapore (two railway companies, a cooling plant, and a university).	The prevalence of vitamin D deficiency: 32.9%, mean serum 25(OH)D: 59.6 nmol/L (23.8 ng/mL). Factors associated with deficiency: office workers, workshop workers (compared to control room workers), and night shift workers.
Dei S, et al, 2024[7]	A cross-sectional study of 168 garment workers in Bangladesh, aged 18 to 47 years, from various garment factories.	Vitamin D insufficiency rate: 86.3%, occurrence of Musculoskeletal Disorders (MSDs): 35.1%. A significant correlation was found between insufficient vitamin D levels and the occurrence of MSDs ($p<0.05$).
Man R, et al., 2017[10]	1139 Chinese, Malay, and Indian adults aged 40 - 80 years old, controls from the Singapore Kidney-Eye Study (nested in SEED study).	Serum vitamin D was suboptimal in 76.1%. Factors associated with increased odds of suboptimal levels of vitamin D: age < 65 years, Malay and Indian ethnicities, higher body mass index, higher HbA1c, higher education, and higher income level.
Díaz P, et al, 2024[13]	A cross-sectional study, 440 University employees (Faculty and administrative staff) in Loja, Ecuador, aged > 18 years.	Hypovitaminosis was identified in 93.4%. Being female and not using sunscreen were associated with lower vitamin D levels.
Jeong H, et al, 2014[15]	A cross-sectional analysis utilizing data from the Korea National Health and Nutrition Examination Survey (KNHANES), with a study population of 5409 workers, 20 – 65 years old in Korea.	The prevalence of vitamin D inadequacy was 69.5% in males and 83.1% in females. Prevalence of vitamin D deficiency among the office workers was 88.1%, which was considerably higher than that of the manufacturing workers (79.0%).
Wang L, et al., [17] 2020	A retrospective review of an electronic hospital database. 2880 office workers in Taiwan from an electronic hospital database, aged 26–65 years.	A high prevalence (61.9%) of hypovitaminosis D. Female, younger age, and winter or spring season were identified as significant predictors of hypovitaminosis D, independent of BMI.

a vitamin D deficiency, ensuring that those most at risk receive the necessary support to optimize their health and well-being. The summary and proposed policy for the prevention of vitamin D deficiency in office workers can be found in **Figure 1**.

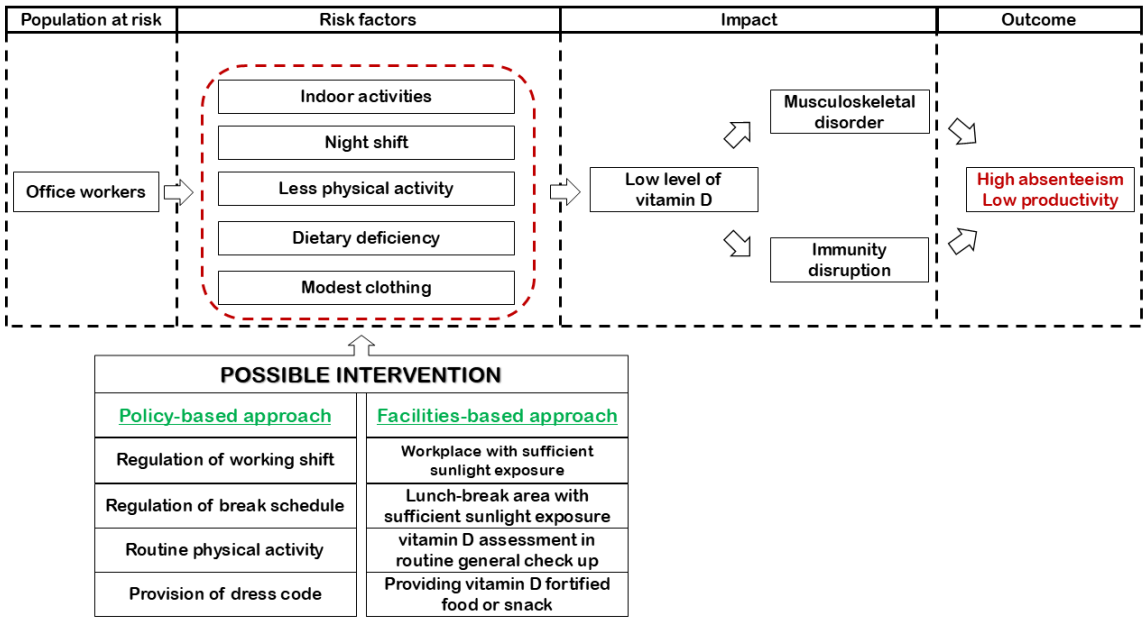

Figure 1. Proposed Intervention for Office Workers as a Population at Risk of Vitamin D Deficiency.

CONCLUSION

Vitamin D deficiency continues to pose a significant challenge in the context of occupational health, particularly among workers with limited sunlight exposure. This condition not only compromises musculoskeletal health, elevating the risk of osteoporosis, pain, and muscle weakness, but also impairs immune system function, increasing susceptibility to infection and disrupting immunologic homeostasis. Furthermore, vitamin D deficiency has been shown to contribute to decreased work productivity through its effects on absenteeism and worker physical capacity. Implementing a systemic strategy should be considered to elevate vitamin D levels among workers to enhance their productivity.

CONFLICT OF INTERESTS

All of the authors declare that there is no conflict of interest.

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