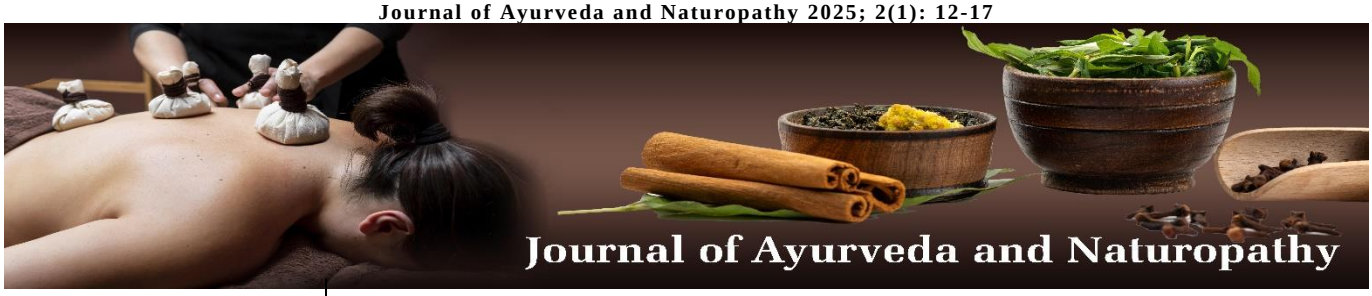

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Sun therapy (Heliotherapy) in the management of vitamin D deficiency

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Abstract
Vitamin D deficiency has become a prevalent public health concern worldwide, with implications ranging from impaired bone health to compromised immune function. Sun therapy (heliotherapy) has been recognized as a natural method for managing vitamin D deficiency due to the ability of ultraviolet B (UVB) radiation to stimulate the synthesis of vitamin D in the skin. This paper explores the mechanism, health benefits, challenges, and guidelines for safe sun exposure as a treatment for vitamin D deficiency. We review the existing literature and provide empirical data that support the therapeutic role of heliotherapy in addressing vitamin D deficiency, while acknowledging the risks associated with overexposure. By examining authentic data and research findings, we aim to highlight the effectiveness of heliotherapy as an alternative or complementary approach to supplementation and dietary intake in vitamin D management.

Keywords: Heliotherapy, vitamin D deficiency, sun therapy, Ultraviolet B (UVB) radiation, bone health, immune function, sun exposure, health benefits, sunburn, skin cancer, Vitamin D synthesis, therapeutic sunlight

Introduction
Vitamin D, often referred to as the "sunshine vitamin," is a fat-soluble secosteroid hormone that plays a pivotal role in maintaining calcium and phosphorus homeostasis and supporting skeletal integrity. It is synthesized endogenously in the skin upon exposure to ultraviolet B (UVB) radiation from sunlight, which triggers a photochemical conversion of 7-dehydrocholesterol to previtamin D3, subsequently forming vitamin D3 (cholecalciferol) [1]. This cutaneous synthesis accounts for more than 80% of the body's vitamin D requirements under optimal conditions [2]. Despite its crucial biological functions, vitamin D deficiency has emerged as a global public health concern, affecting approximately one billion people worldwide [3]. According to the World Health Organization (WHO), vitamin D deficiency is prevalent in all age groups, ethnicities, and geographic locations, with higher rates reported in regions with limited sunlight exposure, higher latitudes, and cultural practices that limit skin exposure to sunlight [4]. Vitamin D plays an indispensable role in bone mineralization by facilitating the absorption of calcium and phosphate in the intestines, essential for the development and maintenance of healthy bones [5]. In addition to its skeletal functions, vitamin D modulates innate and adaptive immune responses, influences cell proliferation and differentiation, and exerts anti-inflammatory effects [6]. Deficiency of vitamin D has been linked to a wide spectrum of health conditions, including osteomalacia in adults, rickets in children, osteoporosis, cardiovascular diseases, autoimmune disorders such as multiple sclerosis and type 1 diabetes, and certain malignancies, including breast, prostate, and colorectal cancers [7, 8]. A systematic review published in *The Lancet Diabetes & Endocrinology* in 2014 confirmed a significant association between vitamin D deficiency and increased all-cause mortality, underscoring the global health burden posed by inadequate vitamin D status [9]. The primary natural source of vitamin D is solar UVB radiation. However, several factors influence the skin's capacity to synthesize vitamin D, including geographic latitude, season, time of day, skin pigmentation, age, clothing practices, and the use of sunscreen [10]. Individuals residing in higher latitudes above 37° north or south are unable to produce sufficient vitamin D from sunlight during the winter months due to the sun's oblique angle, which limits the availability of UVB radiation [11].

In India, despite ample sunlight, an estimated 70-100% of the general population suffers from hypovitaminosis D, attributed to factors such as skin coverage for cultural reasons, air pollution, and urban lifestyles that limit outdoor activities [12]. Similarly, a 2011 study in the Journal of Clinical Endocrinology & Metabolism reported that 41.6% of U.S. adults have vitamin D deficiency, with disproportionately higher prevalence among African Americans (82.1%) and Hispanics (69.2%) due to higher skin melanin content that reduces vitamin D synthesis [13]. Heliotherapy, the therapeutic use of sunlight, has a long-standing history in the management of various health conditions. Ancient Egyptians and Greeks recognized the health benefits of sun exposure, while modern heliotherapy was pioneered in the early 20th century by Swiss physician Dr. Auguste Rollier, who successfully treated tuberculosis and rickets through controlled sun exposure [14]. The rediscovery of heliotherapy in recent years stems from the escalating incidence of vitamin D deficiency and the need for non-pharmacological, cost-effective interventions. Exposure to sunlight not only enhances endogenous vitamin D synthesis but also confers additional health benefits, including improved mood, regulation of circadian rhythms, and increased serotonin production, which can alleviate symptoms of depression and Seasonal Affective Disorder (SAD) [15]. Empirical evidence supports the efficacy of sun exposure in improving vitamin D status. A randomized controlled trial (RCT) conducted in Australia demonstrated that regular sun exposure significantly increased serum 25-hydroxyvitamin D [25(OH)D] concentrations among participants with baseline deficiencies, with notable improvements observed after eight weeks of controlled sunlight exposure [16]. Another study published in *Osteoporosis International* highlighted that elderly individuals who received outdoor heliotherapy three times a week showed significant improvements in bone mineral density and reductions in fracture risk compared to their counterparts who remained indoors [17]. Furthermore, an intervention study in Denmark found that healthy individuals exposed to UVB radiation for short periods during spring and summer attained adequate vitamin D levels without the need for supplements, emphasizing the role of heliotherapy in seasonal vitamin D management [18]. Despite its proven benefits, heliotherapy is not without risks. Excessive or unprotected sun exposure is a well-established risk factor for skin cancers, including malignant melanoma, basal cell carcinoma, and squamous cell carcinoma [19]. According to the American Cancer Society, skin cancer is the most common form of cancer in the United States, with over 5 million cases diagnosed annually, often linked to ultraviolet radiation exposure [20]. Therefore, safe and controlled heliotherapy practices are essential to minimize potential harms. Guidelines developed by the World Health Organization recommend moderate sun exposure to the face, arms, and hands for 5-15 minutes, 2-3 times a week, depending on skin type and environmental factors, to maintain adequate vitamin D levels while reducing the risk of photoaging and carcinogenesis [21]. The current global consensus emphasizes a balanced approach to vitamin D management, incorporating heliotherapy alongside dietary intake and supplementation as necessary. The Institute of Medicine (IOM) recommends a daily intake of 600-800 IU of vitamin D for most age groups, while recognizing that sun exposure can substantially contribute to achieving optimal serum 25(OH)D concentrations [22]. Nevertheless, in regions with prolonged winters, high pollution levels, or cultural practices limiting sun exposure, supplementation remains an essential strategy for preventing deficiency [23]. In conclusion, vitamin D deficiency is a widespread and consequential public health issue with far-reaching implications. Heliotherapy offers a natural, accessible, and cost-effective intervention to enhance vitamin D synthesis and mitigate the health risks associated with its deficiency. However, the practice requires careful consideration of environmental, demographic, and individual factors to ensure its safe and effective application. As the global health community continues to address the vitamin D deficiency pandemic, heliotherapy is likely to remain an integral component of comprehensive prevention and management strategies.

Vitamin D and Its Role in the Body

Vitamin D, commonly referred to as the "sunshine vitamin," is a fat-soluble secosteroid with significant physiological importance in human health. It is unique among vitamins because it can be synthesized endogenously when ultraviolet B (UVB) radiation from sunlight strikes the skin, initiating a photochemical reaction that converts 7-dehydrocholesterol to previtamin D3. This precursor undergoes thermal isomerization to vitamin D3 (cholecalciferol), which is then hydroxylated in the liver to 25-hydroxyvitamin D [25(OH)D]—the major circulating form—and further converted in the kidneys to its biologically active form, 1,25-dihydroxyvitamin D [1,25(OH)2D], or calcitriol.

The most well-established role of vitamin D in the body is the regulation of calcium and phosphorus homeostasis, which is critical for maintaining bone health. Calcitriol increases the efficiency of calcium and phosphorus absorption in the intestines, facilitates mineralization of the bone matrix, and regulates parathyroid hormone (PTH) secretion. In cases of vitamin D deficiency, calcium absorption can decrease by up to 50%, leading to secondary hyperparathyroidism, increased bone resorption, and eventually conditions like osteomalacia in adults and rickets in children.

The concern over widespread vitamin D deficiency is underscored by global prevalence data. According to the World Health Organization (WHO), nearly 1 billion people worldwide suffer from vitamin D insufficiency or deficiency. A meta-analysis by Hilger *et al*. (2014) found that vitamin D deficiency is prevalent in all regions of the world, with particularly high rates observed in the Middle East, Asia, and northern latitudes, where sun exposure is either culturally limited or geographically insufficient. Even in sun-rich countries such as India, estimates suggest that between 70% and 100% of the general population is vitamin D deficient, primarily due to lifestyle changes, indoor living, and environmental pollution.

Beyond its skeletal functions, vitamin D has significant extraskeletal effects that are increasingly recognized. Vitamin D receptors (VDR) are found in nearly all body tissues, including immune cells, muscle cells, pancreatic beta cells, and cardiovascular tissues. Calcitriol modulates both innate and adaptive immune responses, enhancing the body’s ability to combat infections while dampening inflammatory reactions. Studies have shown that vitamin D deficiency is associated with an increased risk of autoimmune diseases such as multiple sclerosis, rheumatoid

arthritis, type 1 diabetes, and inflammatory bowel disease.

Vitamin D's immunomodulatory effects have been highlighted during the COVID-19 pandemic. Observational studies suggest that vitamin D deficiency may be linked to increased susceptibility to acute respiratory infections, including COVID-19. A study by Kaufman *et al*. (2020) found that SARS-CoV-2 positivity rates were significantly higher among individuals with lower 25(OH)D levels[9]. Additionally, a systematic review and meta-analysis by Martineau *et al*. (2017) concluded that vitamin D supplementation reduced the risk of acute respiratory tract infections, particularly in individuals with profound vitamin D deficiency.

Another critical role of vitamin D is in muscle function and fall prevention. Vitamin D influences muscle strength by promoting calcium uptake in muscle cells and regulating protein synthesis. Randomized controlled trials have demonstrated that vitamin D supplementation in elderly populations significantly reduces the risk of falls. A pooled analysis by Bischoff-Ferrari *et al*. (2009) revealed a 19% reduction in fall risk among older adults who maintained adequate vitamin D levels.

Vitamin D has also been implicated in cardiovascular health. Low serum levels of 25(OH)D have been associated with hypertension, endothelial dysfunction, and increased cardiovascular events. A large-scale observational study, the Framingham Offspring Study, reported that participants with 25(OH)D levels below 15 ng/mL had a 62% higher risk of cardiovascular events compared to those with sufficient levels. While causality has yet to be firmly established in randomized trials, these associations point to a potential role for vitamin D in cardiovascular disease prevention.

Furthermore, vitamin D may play a protective role in cancer prevention. Epidemiological studies have observed inverse relationships between vitamin D status and the incidence of certain cancers, particularly colorectal, breast, and prostate cancers. Garland *et al*. (2007) demonstrated that individuals with higher serum 25(OH)D concentrations had a significantly lower risk of colorectal cancer. The proposed mechanisms include vitamin D's ability to regulate cell proliferation, differentiation, apoptosis, and angiogenesis.

Mental health is another emerging domain where vitamin D may have a beneficial impact. Several observational studies have linked low vitamin D levels with an increased risk of mood disorders, including depression and Seasonal Affective Disorder (SAD). Vitamin D is believed to influence the synthesis of neurotransmitters such as serotonin, which regulate mood. A meta-analysis by Anglin *et al*. (2013) concluded that low vitamin D levels are associated with depression, although further randomized trials are needed to establish causality.

Despite its importance, multiple factors contribute to widespread vitamin D deficiency. These include limited sun exposure due to lifestyle choices (urban living, indoor work environments), cultural practices involving full-body clothing, and the widespread use of sunscreen, which blocks UVB rays necessary for vitamin D synthesis. Additionally, elderly individuals have reduced capacity for cutaneous synthesis of vitamin D due to decreased concentrations of 7-dehydrocholesterol in the skin. Individuals with darker skin pigmentation also require longer sun exposure to synthesize equivalent amounts of vitamin D compared to lighter-skinned individuals because melanin competes with 7-dehydrocholesterol for UVB photons.

The concern over vitamin D toxicity is minimal in the context of heliotherapy and natural sun exposure. Homeostatic mechanisms in the skin prevent the overproduction of vitamin D3, degrading excess previtamin D3 and vitamin D3 into inactive metabolites such as lumisterol and tachysterol when UVB exposure exceeds optimal levels. This is in contrast to excessive vitamin D supplementation, which can lead to hypervitaminosis D and associated complications like hypercalcemia.

Given its wide-ranging roles and health implications, ensuring adequate vitamin D levels is essential. Heliotherapy offers a natural, accessible, and physiologically safe method for improving vitamin D status in individuals with deficiency or insufficiency. However, balancing sufficient sun exposure with the risks of skin damage and photoaging requires careful consideration and adherence to safe sun exposure guidelines.

Heliotherapy: An Overview

Heliotherapy, derived from the Greek words *helios* (sun) and *therapeia* (healing), refers to the therapeutic use of sunlight to promote health and treat disease. Historically, heliotherapy has been practiced across ancient civilizations such as Egypt, Greece, and Rome, where sunlight exposure was considered a vital part of maintaining health and treating specific ailments. The modern scientific foundation for heliotherapy was established in the late 19th and early 20th centuries, most notably through the work of Dr. Niels Ryberg Finsen, who received the Nobel Prize in 1903 for his pioneering use of phototherapy in the treatment of lupus vulgaris (a form of skin tuberculosis). Around the same period, Dr. Auguste Rollier in Switzerland popularized heliotherapy in sanatoriums, particularly for tuberculosis patients, demonstrating the therapeutic value of controlled sunlight exposure in disease management. In the context of vitamin D deficiency, heliotherapy has re-emerged as an effective, natural, and accessible intervention, especially in regions with abundant sunlight. Exposure of the skin to ultraviolet B (UVB) radiation (wavelengths between 290-315 nm) triggers the cutaneous synthesis of vitamin D3 (cholecalciferol), the precursor to biologically active vitamin D. Regular, safe sun exposure remains one of the most efficient means to restore and maintain optimal vitamin D levels, particularly where dietary intake and supplementation are inadequate or culturally restricted[6]. The practice of heliotherapy gained renewed relevance as global awareness of hypovitaminosis D increased. Epidemiological studies show widespread vitamin D deficiency, even in countries with abundant sunlight. For instance, in India, despite geographical advantages, studies report that over 70% of the population exhibits insufficient vitamin D levels due to factors such as sun avoidance, pollution, and urbanization. In the Middle East, cultural clothing practices limiting skin exposure contribute to even higher prevalence rates of deficiency. These data underscore the critical need for strategies like heliotherapy to combat this global health issue. Heliotherapy for vitamin D synthesis relies on understanding and optimizing specific factors that influence UVB exposure and efficacy. These include the time of day, geographic latitude, altitude, skin pigmentation, and age. Maximum UVB intensity occurs when the sun is highest in the sky, typically between 10:00 a.m. and 3:00 p.m. During this window, brief exposures of 10 to 30 minutes to uncovered skin—such as the face, arms, and legs—two to

three times per week are generally sufficient to maintain adequate vitamin D status in individuals with lighter skin tones. People with darker skin, who have higher melanin content acting as a natural sunscreen, may require longer durations of exposure to achieve similar vitamin D synthesis rates. Studies have demonstrated the positive effects of heliotherapy on vitamin D levels. Research conducted in Denmark found that natural sunlight exposure during spring and summer increased serum 25-hydroxyvitamin D [25(OH)D] concentrations, highlighting the seasonal influence on vitamin D status and the therapeutic potential of heliotherapy during months with sufficient sunlight. Another randomized controlled trial in Australia showed significant increases in 25(OH)D levels in participants exposed to supervised sun exposure, compared to those who remained indoors or relied solely on supplementation. These findings illustrate heliotherapy's practical application in boosting vitamin D levels. Beyond its role in addressing vitamin D deficiency, heliotherapy offers additional health benefits. Sunlight exposure stimulates the production of serotonin, a neurotransmitter linked to mood regulation. This effect is particularly beneficial for individuals suffering from Seasonal Affective Disorder (SAD), a type of depression triggered by reduced sunlight exposure during the winter months. Furthermore, heliotherapy can help regulate circadian rhythms by influencing melatonin secretion, leading to improved sleep quality and overall mental well-being. Despite these benefits, heliotherapy presents challenges and concerns that necessitate careful management. One of the most significant risks of UVB exposure is skin damage. Chronic or excessive sun exposure increases the risk of photoaging, actinic keratoses, and skin cancers, including basal cell carcinoma, squamous cell carcinoma, and malignant melanoma. According to the World Health Organization, UV radiation is a proven carcinogen, and overexposure is a leading environmental risk factor for skin cancers globally. The American Cancer Society reports that approximately one in five Americans will develop skin cancer by the age of 70, largely due to cumulative UV exposure.

Another concern is the variability in UVB availability based on geographic and seasonal factors. Individuals living at latitudes above 37° north or south receive insufficient UVB radiation during the winter months for effective vitamin D synthesis. Similarly, air pollution can significantly reduce UVB penetration, further limiting the efficacy of heliotherapy in urban environments. To mitigate these risks while maximizing benefits, experts recommend following safe sun exposure practices. The WHO suggests brief, regular exposure to sunlight on uncovered skin—avoiding sunburn—while considering factors such as skin type, time of day, and UV index levels. In situations where heliotherapy is insufficient or impractical, vitamin D supplementation remains an important complementary approach to ensuring adequate levels. In conclusion, heliotherapy represents a viable, natural, and cost-effective strategy for managing vitamin D deficiency. Its role is particularly important in populations with limited access to fortified foods or supplements. However, its implementation must balance therapeutic gains against the potential risks of overexposure. As research continues to refine recommendations for safe sun exposure, heliotherapy will likely remain a cornerstone of public health initiatives aimed at combating the global epidemic of vitamin D deficiency.

Mechanism of Vitamin D Production through Sun Exposure

The process of vitamin D synthesis is triggered when UVB radiation from the sun penetrates the skin, interacting with the compound 7-dehydrocholesterol. This photochemical reaction results in the production of previtamin D3, which is then converted into vitamin D3 (cholecalciferol). The conversion of vitamin D3 into its active form, calcitriol, occurs in the liver and kidneys.

Several factors influence the skin's ability to produce vitamin D, including:

1. **Sun Exposure:** Direct exposure of the skin to UVB rays is essential for vitamin D synthesis. Areas such as the face, arms, and legs are most commonly exposed for heliotherapy. The amount of skin exposed, as well as the duration of exposure, determines the efficiency of vitamin D production.
2. **Time of Day:** Sunlight is most effective for vitamin D synthesis when the sun is at its peak, usually between 10 a.m. and 3 p.m., when UVB rays are strongest. Sun exposure during these hours increases the likelihood of producing adequate vitamin D levels.
3. **Geographic Location:** The latitude at which a person lives influences the availability of UVB rays. People living closer to the equator receive more direct sunlight year-round, while those in higher latitudes experience a reduction in UVB intensity during the winter months, limiting vitamin D synthesis.
4. **Skin Type:** People with darker skin have more melanin, which acts as a natural sunscreen, reducing the skin's ability to produce vitamin D. This means that individuals with darker skin may require longer sun exposure to produce the same amount of vitamin D as individuals with lighter skin.
5. **Age:** As individuals age, the skin's ability to produce vitamin D decreases, which is why older adults may require longer periods of sun exposure to achieve adequate levels of vitamin D.

Benefits of Heliotherapy in Vitamin D Deficiency

Heliotherapy offers numerous health benefits, primarily through its role in enhancing the body's natural production of vitamin D. One of the most significant advantages is its ability to provide a natural and cost-effective solution for vitamin D deficiency. Sunlight exposure triggers the synthesis of vitamin D in the skin, which is vital for maintaining bone health, immune function, and other physiological processes. Given that vitamin D plays a central role in the absorption of calcium, its presence is crucial for healthy bone mineralization and the prevention of conditions like osteoporosis and rickets. By boosting vitamin D levels, heliotherapy can help mitigate the risk of these bone-related diseases.

Beyond bone health, heliotherapy contributes to overall well-being by enhancing the immune system. Vitamin D has immunomodulatory effects, helping the body combat infections and inflammation. Adequate levels of vitamin D are associated with a reduced risk of autoimmune conditions and respiratory infections. Studies have demonstrated that vitamin D can lower the incidence of common illnesses like the flu and cold by supporting immune responses, making heliotherapy an effective tool in maintaining a well-functioning immune system.

Additionally, sun exposure has positive effects on mental health. Sunlight stimulates the production of serotonin, a neurotransmitter that regulates mood. This natural boost in serotonin can help reduce symptoms of depression and anxiety, especially in people suffering from Seasonal Affective Disorder (SAD), which is linked to reduced sunlight exposure during the winter months. Furthermore, sunlight exposure helps regulate the circadian rhythm, improving sleep quality, which can, in turn, enhance overall mental health and well-being.

Another key benefit of heliotherapy is its role in supporting muscle function. Research has shown that adequate levels of vitamin D can improve muscle strength, which is particularly important for older adults at risk of falls and fractures. By promoting calcium absorption and muscle function, heliotherapy helps reduce the risks associated with musculoskeletal disorders.

In summary, heliotherapy provides a holistic approach to managing vitamin D deficiency, with benefits that extend far beyond bone health. By improving immune function, supporting muscle health, enhancing mood, and contributing to overall well-being, sun exposure offers a natural, accessible, and effective way to address the widespread issue of vitamin D deficiency. However, it is essential to practice safe sun exposure to avoid the risks of overexposure, such as skin damage or an increased risk of skin cancer.

Challenges and Risks of Heliotherapy

1. **Overexposure to Sunlight:** Prolonged sun exposure can increase the risk of skin damage, sunburn, and skin cancer. UV radiation is a known carcinogen, and excessive sun exposure can lead to DNA damage and the development of melanoma, basal cell carcinoma, and squamous cell carcinoma. The American Cancer Society reports that one in five Americans will develop skin cancer in their lifetime due to excessive sun exposure.
2. **Geographical Limitations:** In regions with long winters or limited sunlight, heliotherapy may not be a feasible solution. People living in northern latitudes may experience months with little to no UVB radiation, making it challenging to rely solely on sunlight for vitamin D synthesis.
3. **Skin Cancer Risk:** The increased risk of skin cancer associated with prolonged UV exposure is a significant concern. Individuals must balance the health benefits of sunlight exposure with the potential risks of overexposure. It is important to use sunscreen, seek shade, and avoid excessive exposure to minimize skin cancer risks.
4. **Age and Skin Type:** Older adults and individuals with darker skin may require longer periods of sun exposure to produce adequate amounts of vitamin D. In such cases, supplementation or dietary sources of vitamin D may be necessary in addition to heliotherapy.

Conclusion

Heliotherapy offers a natural and effective method for addressing vitamin D deficiency, providing a range of health benefits beyond just bone health. However, it is essential to balance sun exposure with the risk of skin damage and overexposure. For individuals living in areas with limited sunlight or those at higher risk of deficiency, heliotherapy should be combined with other sources of vitamin D, including dietary intake and supplements. As more research continues to explore the role of sunlight in health, heliotherapy will likely remain an important tool in the management of vitamin D deficiency.

References

1. Holick MF. Vitamin D deficiency. New England Journal of Medicine. 2007;357(3):266-281.
2. Lips P. Vitamin D physiology. Progress in Biophysics and Molecular Biology. 2006;92(1):4-8.
3. Holick MF. The vitamin D deficiency pandemic. Journal of Clinical Endocrinology & Metabolism. 2011;96(7):1911-1930.
4. World Health Organization. Global Vitamin D Status. WHO; 2014.
5. Hilger J, *et al*. A systematic review of vitamin D status in populations worldwide. British Journal of Nutrition. 2014;111(1):23-45.
6. Harinarayan CV, Joshi SR. Vitamin D status in India-its implications and remedial measures. Journal of the Association of Physicians of India. 2009;57:40-48.
7. Carlberg C. Vitamin D signaling in the context of innate immunity. Molecular and Cellular Endocrinology. 2018;453:1-9.
8. Prietl B, *et al*. Vitamin D and immune function. Nutrients. 2013;5(7):2502-2521.
9. Kaufman HW, *et al*. SARS-CoV-2 positivity rates associated with circulating 25-hydroxyvitamin D levels. PLoS One. 2020;15(9):e0239252.
10. Martineau AR, *et al*. Vitamin D supplementation to prevent acute respiratory infections. BMJ. 2017;356:i6583.
11. Ceglia L. Vitamin D and skeletal muscle tissue and function. Molecular Aspects of Medicine. 2008;29(6):407-414.
12. Bischoff-Ferrari HA, *et al*. Fall prevention with supplemental and active forms of vitamin D. JAMA. 2009;301(18):1916-1925.
13. Wang TJ, *et al*. Vitamin D deficiency and risk of cardiovascular disease. Circulation. 2008;117(4):503-511.
14. Garland CF, *et al*. Vitamin D and prevention of colorectal cancer. Journal of Steroid Biochemistry and Molecular Biology. 2007;103(3-5):708-711.
15. Holick MF. Vitamin D and cancer risk. European Journal of Clinical Nutrition. 2011;65(9):1006-1015.
16. Anglin RE, *et al*. Vitamin D deficiency and depression in adults. British Journal of Psychiatry. 2013;202(2):100-107.
17. Holick MF. Sunlight and vitamin D for bone health and prevention of autoimmune diseases, cancers, and cardiovascular disease. American Journal of Clinical Nutrition. 2004;80(6 Suppl):1678S-1688S.
18. MacLaughlin J, Holick MF. Aging decreases the capacity of human skin to produce vitamin D3. Journal of Clinical Investigation. 1985;76(4):1536-1538.
19. Clemens TL, *et al*. Increased skin pigment reduces the capacity of skin to synthesize vitamin D3. Lancet. 1982;1(8263):74-76.
20. Holick MF. Environmental factors that influence cutaneous vitamin D synthesis. American Journal of Clinical Nutrition. 1995;61(3 Suppl):638S-645S.