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Literature Review

Vitamin D and Men's Health: Literature Review

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ABSTRACT

Vitamin D, sometimes referred to as the "sunshine vitamin," provides a number of benefits beyond bone health. In men, it has a role in fertility, metabolic regulation, immunological modulation, and healthy aging. By analyzing its production, mechanisms, physiological functions, and specific effects on male health across several systems, this article aims to clarify the importance of vitamin D in preventative and therapeutic health measures. Vitamin D, previously linked to calcium and bone homeostasis, is now a crucial regulator in various physiological domains affecting men's health. This comprehensive review explores the production, metabolism, and several mechanisms of action of vitamin D, with particular attention to its impact on male fertility, metabolic syndrome, immunological regulation, aging, obesity, and chronic diseases such as type 2 diabetes and autoimmune disorders. According to recent studies, vitamin D receptors are found in male reproductive and metabolic organs, and adequate vitamin D levels are linked to improved musculoskeletal integrity, insulin sensitivity, hormonal balance, and semen quality. The study explores the impact of vitamin D deficiency, a prevalent issue in men globally, and suggests interventional strategies such as supplementation and lifestyle modifications. Vitamin D is a crucial regulator of male physiological and pathological processes, according to all available research, and as such, it merits more attention in clinical practice and public health policy.

Introduction

A secosteroid hormone, vitamin D has long been recognized for its role in preserving calcium and bone homeostasis. Today, it is a crucial regulator of several physiological systems inside the body. More people are becoming aware of its importance for men's health, especially in regard to aging, metabolic balance, immunological response, and reproductive function. Worldwide, vitamin D insufficiency is incredibly common in men and its causes range from age and lifestyle changes to obesity and insufficient sun exposure [1][2]. Even while hypovitaminosis D is easily corrected with dietary supplements and lifestyle changes, it nevertheless presents significant health risks for males, impacting reproductive metrics, raising the risk of chronic illnesses, and hastening age-related functional decline.

The objectives of this review are to evaluate the synthesis and metabolism of vitamin D critically, elucidate its mechanisms of action, and explore its role in several male-specific health domains.Current study discoveries that relate vitamin D status to age-related health issues, metabolic syndrome, autoimmune diseases, and male fertility are highlighted. Comprehending these correlations might facilitate the implementation of focused public health initiatives and personalized medicine methodologies intended to maximize vitamin D levels in males.

Methods

1. Vitamin D Synthesis and Metabolism

When 7-dehydrocholesterol is exposed to ultraviolet B (UVB) rays, it is converted to cholecalciferol (vitamin D3), which is the main source of vitamin D in the skin [1]. The primary circulating form, 25-hydroxyvitamin D [25(OH)D], is then created by hydroxylation in the liver (the main circulating form and most accurate measure of vitamin D status), by the enzyme 25-hydroxylase (CYP2R1) [3] , The first is the production of 25-hydroxyvitamin D [25(OH)D], the main circulating form and most accurate measure of vitamin D status, in the liver by the enzyme 25-hydroxylase (CYP2R1) [3]. 1α-hydroxylase (CYP27B1) is mainly responsible for the second hydroxylation, that occur in in the kidneys which transforms 25(OH) D into the physiologically active form 1,25-dihydroxyvitamin D [1,25(OH)2D], often referred to as calcitriol [4]. By attaching itself to the vitamin D receptor (VDR), a nuclear transcription factor that affects the expression of more than 900 genes, this active form produces its effects [5].

Alternatively, vitamin D can be obtained through food through supplements, fortified dairy products, and fatty fish. There are two primary forms: vitamin D3 (found in animal products) and vitamin D2 (ergocalciferol), which is derived from plants.

Feedback processes involving parathyroid hormone (PTH), fibroblast growth factor 23 (FGF23), calcium, and phosphate levels tightly control the metabolism of vitamin D. Specifically, low calcium and high PTH enhance the formation of calcitriol, whereas FGF23 and high phosphate levels block 1α-hydroxylase, lowering calcitriol synthesis [6].

Significantly, CYP27B1 extrarenal expression has been found in a number of organs, including the placenta, prostate, colon, and immune cells. This suggests that calcitriol is produced locally for autocrine and paracrine signaling [7]. Male health may be significantly impacted by this, especially in areas like the prostate and testis where local vitamin D activity may affect immunological and reproductive function.

Even in the presence of adequate sun exposure, vitamin D metabolism can be hampered by obesity, age, liver/kidney illness, and some drugs (e.g., glucocorticoids, anticonvulsants) [8]. This can result in a functional insufficiency. Therefore, an understanding of the nuances of vitamin D synthesis and metabolism is necessary for the diagnosis and treatment of disorders connected to vitamin D in males. as shown in table 1[1].

Table 1: Factors Affecting Vitamin D Levels in Men

Factor	Impact on Vitamin D	Notes
Age	↓ Reduced skin synthesis	Common in elderly males
Overweight/Obesity	↓ Sequestration in adipose tissue	Lowers bioavailability
Skin Type	↓ Darker skin synthesizes less vitamin D	Requires longer sun exposure
Lifestyle	↓ Indoor lifestyle limits sun exposure	Major global factor
Liver/Kidney Diseases	↓ Impaired vitamin D metabolism	Causes functional deficiency
Certain Medications	↓ Alter metabolism (e.g., glucocorticoids)	Common in chronic illnesses

2. Vitamin D Mechanisms of Action

The main way that vitamin D works is by attaching itself to the vitamin D receptor (VDR), which is expressed in a number of organs outside of the skeletal system, including as the brain, testes, pancreas, and immune cells. Once active, the intracellular vitamin D receptor (VDR)-vitamin D complex regulates the expression of genes linked to hormone regulation, insulin sensitivity, immune response, and calcium homeostasis.

There are both genetic and non-genomic ways that vitamin D influences biology. The classical genetic mechanism states that 1, 25-dihydroxyvitamin D, is bound by the intracellular VDR, a member of the nuclear receptor superfamily. The retinoid X receptor (RXR) and the VDR heterodimerize upon activation to change the transcription of the target gene. The complex then binds to certain vitamin D response elements (VDREs) in the target genes' promoter regions [5].

According to Bouillon et al., VDRs are expressed in over 30 different tissues, including immune cells, skeletal muscle, testes, prostate, intestines, kidneys, pancreatic islets, and bones. The pleiotropic effects of vitamin D are supported by this wide expression. Vitamin D controls immunological response, cell division and proliferation, apoptosis, calcium-phosphate equilibrium, and hormone production via these genetic pathways [6].

Vitamin D has non-genomic effects that happen faster quickly and involve membrane-bound receptors like the membrane-associated rapid response steroid-binding (MARRS) protein. Without requiring direct gene transcription, these activities trigger physiological reactions by activating second messenger systems such as calcium channels, protein kinase C, and phospholipase C [4].

Through these parallel routes, vitamin D may regulate a variety of biological processes, including hormone synthesis, oxidative stress reduction, and inflammation control—all of which are critical for the health of men.

3. The Physiological Functions of Vitamin D

In addition to controlling calcium and phosphate, vitamin D is essential for immunological response, cardiovascular control, muscular function, and inflammation management. A more balanced immunological response, a decreased risk of cardiovascular illnesses, and increased muscle strength are all linked to men's optimal vitamin D levels. The systemic effects of vitamin D that are frequently disregarded in clinical studies are highlighted in this section.

Vitamin D is essential for bone and mineral metabolism, and in men, it plays a crucial role in various physiological applications.

Musculoskeletal health: Vitamin D is crucial for maintaining musculoskeletal health, enhancing muscular strength, reducing fracture risk, and ensuring the integrity of the skeleton [9]. immunological regulation: Vitamin D plays a crucial role in regulating T-cell differentiation, cytokine production, and macrophage activation, thereby influencing both innate and adaptive immunological responses [7].

Cardiovascular health: Vitamin D deficiency is associated with hypertension, endothelial dysfunction, and increased risk of cardiovascular disease [10].

Neurocognitive function: Emerging evidence links low vitamin D levels with cognitive impairment and mood disorders in men, particularly the elderly [11].

These many functions highlight how crucial it is to keep men's vitamin D levels at their ideal levels for general physiological balance and disease prevention.

4. Vitamin D and Male Fertility

According to recent research, vitamin D has a good impact on male reproductive health. The VDRs have a direct function in spermatogenesis and androgen production since they are present in the testes, prostate, and sperm cells. Higher testosterone levels, greater sperm motility, and enhanced semen characteristics are all associated with adequate vitamin D levels. Vitamin D influences testosterone production and modulates reproductive hormones through its action on Leydig cells in the testes [12]. The possibility of vitamin D supplementation as an adjuvant treatment for male infertility is examined in this section. Display Table 2.

Table 2: Association of Vitamin D with Male Reproductive Functions

Function/Parameter	Role of Vitamin D	Supporting Source
Semen Quality	↑ Enhances motility and concentration	(13)
Testosterone Levels	↑ Increases total and free testosterone	(12)
Sperm Cell Function	↑ Activates calcium channels for motility	(14)
Overall Fertility	↑ Supports testicular and hormonal functions	Multiple reviews

Optimal vitamin D levels are intimately associated with male fertility; several studies have found a relationship between blood 25(OH)D levels and sperm quality, sexual function, and reproductive hormone concentrations. The testis, epididymis, prostate, and spermatozoa have been found to have vitamin D receptors (VDRs) and enzymes that metabolize vitamin D, indicating a local function in male reproduction [13].

Lower testosterone levels and poorer semen quality are linked to vitamin D insufficiency, according to aresearch by Lerchbaum et al. Vitamin D supplementation enhanced acrosome response and sperm motility in experimental animals [12]. Additionally, males with adequate vitamin D status typically have superior erectile function and greater levels of free and total testosterone, both of which are important indicators of male reproductive potential [14].

By improving intracellular calcium signaling in sperm cells, regulating spermatogenesis and hormone production in Leydig and Sertoli cells, and lowering oxidative stress in the testes, vitamin D may have a positive reproductive impact [15]. Interventional trials, however, produce conflicting outcomes; further high-quality randomized controlled trials are required to validate these results.

5. Obesity and Vitamin D Deficiency in Men

Obesity is both the cause and the effect of vitamin D deficiency. Adipose tissue stores vitamin D since it is fat-soluble, which reduces its bioavailability in obese individuals. Low vitamin D levels in obese men exacerbate insulin resistance and inflammation, and treating this deficiency can aid in metabolism improvement.

Obesity is a significant risk factor for vitamin D deficiency in men, influenced by factors such as volumetric dilution, reduced outdoor activity, altered metabolism, and vitamin D sequestration in adipose tissue [16]. Obese men often have low 25(OH)D levels, potentially worsening metabolic issues like insulin resistance, dyslipidemia, and chronic inflammation. Vitamin D deficiency in male obesity is linked to hypogonadism, infertility, and muscle function.

Vitamin D supplementation's effects on obese men vary based on dosage, baseline levels, and adiposity. Some studies suggest higher doses are needed to overcome adipose sequestration, while others show improvements in insulin sensitivity and inflammatory markers [13].

6. Vitamin D and Type 2 Diabetes in Men

Vitamin D deficiency is linked to decreased insulin production and elevated insulin resistance, which is crucial for diabetes pathophysiology. Deficits in males lead to worse glycemic control and a higher risk of type 2 diabetes. This section evaluates mechanisms and interventional trials to support vitamin D's role in diabetes prevention and management.

Insulin sensitivity, glucose metabolism, and pancreatic β-cell activity are all significantly influenced by vitamin D, and these factors affect the pathophysiology of type 2 diabetes mellitus (T2DM). The vitamin D receptor, present in skeletal muscle, adipose tissue, immunological cells, and pancreatic islets, interacts with the active form of vitamin D (1,25-dihydroxyvitamin D) [18].

According to epidemiological research, boys' blood 25-hydroxyvitamin D concentrations and their risk of type 2 diabetes are significantly inversely correlated [19]. Increased insulin resistance, persistent low-grade inflammation, and dyslipidemia are linked to vitamin D deficiency and are all factors in the development of diabetes and the metabolic syndrome.Furthermore, men who lead sedentary lives and have abdominal obesity are more likely to have hypovitaminosis D, which increases the risk of insulin resistance [20].

Though recent meta-analyses indicate modest improvements in insulin sensitivity and fasting glucose in vitamin D-deficient individuals, especially men with prediabetes, randomized controlled trials have yielded conflicting results regarding the effect of vitamin D supplementation on glycemic control [21] [22] . Thus, maintaining a sufficient level of vitamin D may serve as a preventative and supplementary therapy strategy for male patients who have type 2 diabetes or are at risk for developing it.

7. Aging and Vitamin D

Men's skin's capacity to produce vitamin D declines with age, which leads to a general deficit. Expression of VDR and vitamin D metabolism are similarly impacted by age-related changes.

Physiological changes brought on by aging have a negative effect on the production, metabolism, and function of vitamin D. Even with adequate sun exposure, the skin's diminished ability to synthesize vitamin D3 as a result of lower levels of 7-dehydrocholesterol is one of the most notable age-related alterations [23]. Furthermore, aging may cause a reduction in renal 1α-hydroxylase activity, which would reduce the conversion of 25(OH)D to its active form, $1,25(OH)_2D$ [24].

Due to decreased outdoor exercise, comorbidities, polypharmacy (such as glucocorticoids and anticonvulsants), and inadequate food, older men are more susceptible to vitamin D deficiency [1]. In older men, vitamin D insufficiency has been associated with cognitive impairment, sarcopenia, frailty, diminished muscular strength, and an increased risk of falls [25] [26].

Vitamin D supplementation has been shown to assist older men preserve musculoskeletal function, enhance balance, and reduce their risk of fracture when taken in combination with calcium [27]. The Endocrine Society recommends 800–1000 IU of vitamin D daily for people 65 and older to maintain optimal blood 25(OH)D levels (>30 ng/mL), which may support healthy aging and functional independence.

8. Vitamin D and Autoimmune Disorders in Men

Vitamin D's immunomodulatory qualities are crucial for autoimmune disease prevention and treatment. Vitamin D levels in men are linked to multiple sclerosis, rheumatoid arthritis, and inflammatory bowel disease. This study investigates how vitamin D affects immunological tolerance and T-cell responses, potentially targeting male-specific autoimmune disorders.

Vitamin D, specifically 1, 25-dihydroxyvitamin D3, is recognized as a crucial immune system regulator, with significant implications for autoimmune diseases. Its active form, 1,25-dihydroxyvitamin D3, has immunomodulatory effects by binding to the vitamin D receptor in immune cells like dendritic cells, macrophages, and CD4+ and CD8+ T lymphocytes [28]. Vitamin D inhibits pro-inflammatory cytokines like IL-2, TNF-α, and IFN-γ while promoting the growth and function of regulatory T cells, thereby maintaining immune tolerance and had constant function in adaptive immunity as well as inherent immunity [29] [30].

Ngo et al. stated that whereas autoimmune disorders are more prevalent in women, men often experience worse outcomes and more severe disease development [31]. Vitamin D insufficiency may be a risk factor for autoimmune diseases that are common in males, such as multiple sclerosis, rheumatoid arthritis, type 1 diabetes, and inflammatory bowel disease (IBD), according to recent study [32] [33]. For example, vitamin D supplementation has been linked to decreased inflammatory activity in MS, and low blood 25(OH)D levels have been negatively correlated with the recurrent incidence and severity of the condition [34].

Vitamin D's significance in controlling autoimmune diseases is further supported by the notion that it affects the epigenetic regulation of immune-related genes. Vitamin D supplementation may help lower disease activity and improve the effectiveness of immunosuppressive medications, according to encouraging but conflicting results from clinical trials assessing vitamin D's impact on autoimmune disorders [35]. Our results emphasize the necessity for tailored vitamin D screening and remediation programs for male patients with autoimmune diseases or at risk for developing them. Display Table 3.

Table 3: Impact of Vitamin D Deficiency on Common Male Health Conditions

Health Condition	Vitamin D–Related Mechanism	Evidence Source
Obesity	↑ Inflammation and insulin resistance	(16)
Type 2 Diabetes	↓ Insulin secretion and sensitivity	(18)
Cardiovascular Disease	↑ Hypertension and arterial stiffness	(10)
Muscle Weakness/Sarcopenia	↓ Muscle strength and balance	(9)
Mood & Cognitive Disorders	↓ Lin ked to depression and cognitive decline	(11)

9. Best Sources of Vitamin D for Men

Vitamin D is primarily obtained from moderate sun exposure and food sources like fatty fish, egg yolks, fortified dairy products, and supplements. Factors like latitude, skin pigmentation, and lifestyle choices affect vitamin D production. The article also provides recommendations for suitable supplements.

A combination of food consumption, supplementation, and endogenous synthesis from sun exposure can help men reach optimal vitamin D levels. Maintaining adequate serum 25(OH) D concentrations and reducing the health hazards associated with deficiencies are made possible by the distinct contributions of each of these sources.

Sunlight Exposure

The most efficient and natural way to get vitamin D is through cutaneous synthesis. Skin 7-dehydrocholesterol is converted to previtamin D3 by ultraviolet B (UVB) light, and this previtamin is then thermally isomerized to vitamin D3 [36].

Effective synthesis is, however, restricted by a number of variables, such as indoor lifestyles, darker skin pigmentation, sunscreen usage, and aging. As a result, depending just on sunshine is frequently inadequate, especially at northern latitudes or throughout the winter.

Dietary Sources

Few foods naturally contain significant amounts of vitamin D. These include:

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A. Fatty fish such as salmon, mackerel, and sardines
B. Fish liver oils (e.g., cod liver oil)
C. Egg yolks
D. Liver
E. Fortified foods (e.g., dairy products, cereals, plant-based milks, and orange juice) Table 4. Show Dietary Sources of Vitamin D and Approximate Content

Particularly in males with poor diets or limited access to nutrient-rich foods, the bioavailability of vitamin D from these meals varies, and consumption is frequently below the recommended dietary allowances (RDAs) [37].

Table 4: Dietary Sources of Vitamin D and Approximate Content

Food Source	Type of Vitamin D	Approximate Content (per 100 g)
Salmon	D3 (Cholecalciferol)	400–1000 IU
Cod Liver Oil	D3	~4500 IU
Egg Yolk	D3	~37 IU
Fortified Milk	D2 or D3	~100 IU per cup
Vitamin D Supplements	D2 or D3	400–5000 IU per capsule

Supplementation

Optimal 25(OH)D levels can be restored and maintained with the use of vitamin D supplementation. Because of its greater effectiveness and longer half-life, vitamin D3 (cholecalciferol) is typically chosen over vitamin D2 (ergocalciferol) [38]. For adults at risk of deficiency, the Endocrine Society suggests 1,500–2,000 IU daily; however, obese people, the elderly, and people with malabsorption disorders may need greater dosages [39]. Table 5. shows recommended daily intake of vitamin D by age and risk category.

Body weight, comorbid diseases, and baseline blood 25(OH)D levels should all be taken into account when customizing a supplement regimen. To prevent toxicity, periodic monitoring should be done.

Table 5: Recommended Daily Intake of Vitamin D by Age and Risk Category

Group	Recommended Daily Dose (IU/day)	Notes
Healthy Adult Men (19–50 years)	600–800	General guidelines
Older Men (≥65 years)	800–1000	For bone and muscle support
Obese Men	2000–4000	Based on BMI and adiposity
Men with Chronic Deficiency	>4000 (under medical supervision)	Requires blood monitoring

Conclusion

Vitamin D is essential for maintaining men's health. It's crucial to keep men's vitamin D levels at their ideal levels for general physiological systems balance inside the body and for disease prevention. More people are becoming aware of its importance for men's health, especially in regard to aging, metabolic balance and immunological response. Regarding reproductive function vitamin D has a good impact on male reproductive health.

Physiological changes brought on by aging have a negative effect on the production, metabolism, and function of vitamin D.

Vitamin D deficiency is linked to decreased insulin production and elevated insulin resistance Thus, maintaining a sufficient level of vitamin D may serve as a preventative and supplementary therapy.

Vitamin D, specifically 1, 25-dihydroxyvitamin D3, is recognized as a crucial immune system regulator, with significant implications for autoimmune diseases

Even while vitamin D levels may be changed by diet, supplementation, and sun exposure, deficiencies are nevertheless common, especially in older and obese males. In order to clarify the best dosage methods and long-term effects of vitamin D treatments catered to the physiological requirements of men, future research should give top priority to carefully planned clinical studies.

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Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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