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REVIEW ARTICLE

TITLE:

VITAMIN D AND FATTY LIVER DISEASE: PATHOPHYSIOLOGICAL LINKS AND THERAPEUTIC POTENTIAL

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VITAMIN D AND FATTY LIVER DISEASE: PATHOPHYSIOLOGICAL LINKS AND THERAPEUTIC POTENTIAL

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ABSTRACT

Fat accumulation within hepatocytes is a defining feature of Fatty Liver Disease (FLD), a condition that includes Non-Alcoholic Fatty Liver Disease (NAFLD), its more severe form Non-Alcoholic Steatohepatitis (NASH), and Alcoholic Fatty Liver Disease (ALD). NAFLD, in particular, is closely linked to metabolic disturbances such as insulin resistance, chronic low-grade inflammation, and dyslipidemia. In recent years, growing attention has been directed toward vitamin D deficiency as a potential factor contributing to both the development and progression of this condition. Vitamin D, a fat-soluble secosteroid, is widely recognized for its role in calcium homeostasis, but it also plays important roles in immune function and metabolic regulation.This review brings together current evidence on vitamin D metabolism and explores its involvement in key processes relevant to NAFLD, including hepatic lipid handling, insulin sensitivity, inflammatory responses, and fibrotic changes. It also examines the mechanistic pathways through which vitamin D deficiency may influence disease progression. In addition, findings from epidemiological studies, interventional research, and clinical trials are evaluated to better understand the potential role of vitamin D supplementation in the management of NAFLD. By integrating these diverse lines of evidence, this review aims to provide a clear and evidence-based perspective for clinicians and researchers addressing NAFLD and its associated metabolic complications.

Keywords: Vitamin D; fatty liver disease; NAFLD; Non-Alcoholic Steatohepatitis; insulin resistance; inflammation

1. INTRODUCTION

Fatty liver disease (FLD) encompasses a spectrum of disorders characterized by the excessive accumulation of lipids, primarily triglycerides,within hepatocytes. Although often initially asymptomatic, FLD can progress to serious conditions including cirrhosis, liver failure, and hepatocellular carcinoma (HCC). The disease is broadly classified based on its etiology. Non-Alcoholic Fatty Liver Disease (NAFLD) refers to fat accumulation in individuals consuming little or no alcohol; it is the most prevalent chronic liver disease globally, affecting over 25% of the adult population and strongly linked to metabolic syndrome, type 2 diabetes, obesity, and insulin resistance(ix). Non-Alcoholic Steatohepatitis (NASH), a more severe subtype, involves concurrent hepatic inflammation and cellular damage in addition to steatosis, and carries a heightened risk of progression to fibrosis, cirrhosis, and HCC (xxvi). Recent nomenclature revisions have introduced Metabolic-associated Steatotic Liver Disease (MASLD) as a more inclusive descriptor that emphasizes the metabolic origins of these conditions (lxv).

1.1 Prevalence of Fatty Liver Disease

NAFLD affects approximately 25% of adults worldwide, with prevalence expected to increase in parallel with rising rates of obesity, sedentary lifestyles, and type 2 diabetes(lxiv). Rates are particularly high in

rapidly industrializing regions such as South Asia and the Middle East, where certain ethnic groups, including Hispanics and South Asians demonstrate a heightened genetic susceptibility. In some high-obesity communities, NAFLD prevalence exceeds 40–50% (lxiii). Approximately 80% of NAFLD patients are overweight or obese, underscoring the central role of the global obesity epidemic (xxxv). The economic burden of NAFLD, particularly when it progresses to NASH or cirrhosis, is substantial: annual healthcare costs in nations such as the United States may reach several billion dollars, highlighting the urgent need for early detection and intervention (lxv).

1.2 Risk Factors and Clinical Presentation

Multiple modifiable and non-modifiable risk factors contribute to NAFLD development. Visceral obesity and abdominal adiposity drive ectopic lipid deposition in the liver. Impaired insulin signaling, a hallmark of insulin resistance, promotes fatty acid mobilization from adipose tissue to the liver (xxxiii). Oxidative stress, arising from free fatty acid accumulation and reactive oxygen species (ROS) production, causes hepatocyte injury and activates hepatic stellate cells (HSCs), initiating fibrogenesis (liv,viii). Dyslipidemia, elevated triglycerides, and metabolic syndrome collectively amplify the risk. Genetic susceptibility is also well-documented; the PNPLA3 gene variant, encoding patatin-like phospholipase domain-containing protein 3, is strongly associated with increased liver fat accumulation and NASH progression (lv).Clinically, NAFLD is often silent in its early stages. Diagnostic indicators emerging with disease progression include elevated serum transaminases (ALT and AST), right upper quadrant discomfort, and in advanced disease jaundice and splenomegaly secondary to portal hypertension. Liver biopsy remains the gold standard for distinguishing NAFLD from NASH, though non-invasive tools such as ultrasound, CT, MRI, transient elastography, and serum biomarker panels are increasingly used in practice (ii).

This review examines the emerging relationship between vitamin D deficiency and the development and progression of NAFLD, with particular attention to the molecular and metabolic mechanisms involved. It discusses the role of vitamin D in hepatic lipid metabolism, insulin resistance, inflammation, and fibrogenesis, while also evaluating epidemiological evidence, experimental findings, and clinical studies on vitamin D supplementation. By bringing these strands of evidence together, this review aims to clarify whether vitamin D may serve not only as a biomarker of disease severity but also as a potential therapeutic target in NAFLD management.

2. VITAMIN D METABOLISM AND BIOLOGICAL ROLES

Vitamin D is a fat-soluble secosteroid with diverse physiological functions extending beyond skeletal health. Synthesis begins in the skin, where UVB radiation converts 7-dehydrocholesterol to pre-vitamin D3, which is subsequently thermally isomerized to cholecalciferol (vitamin D3). Dietary sources include animal-derived foods such as fatty fish, egg yolks, and fortified products. Following absorption or cutaneous synthesis, vitamin D3 enters systemic circulation and is transported to the liver.

In the liver, the enzyme 25-hydroxylase (encoded by CYP2R1) hydroxylates vitamin D3 at carbon-25, producing 25-hydroxyvitamin D [25(OH)D, calcidiol], the primary circulating and clinically measured form of vitamin D (xxvii). However, 25(OH)D is biologically inactive and requires further conversion in the kidneys, where 1-α-hydroxylase (encoded by CYP27B1) hydroxylates it at the 1-position to generate 1,25-dihydroxyvitamin D [calcitriol] — the fully active hormone. This renal activation is tightly regulated by serum

calcium, phosphate, and parathyroid hormone (PTH) concentrations.

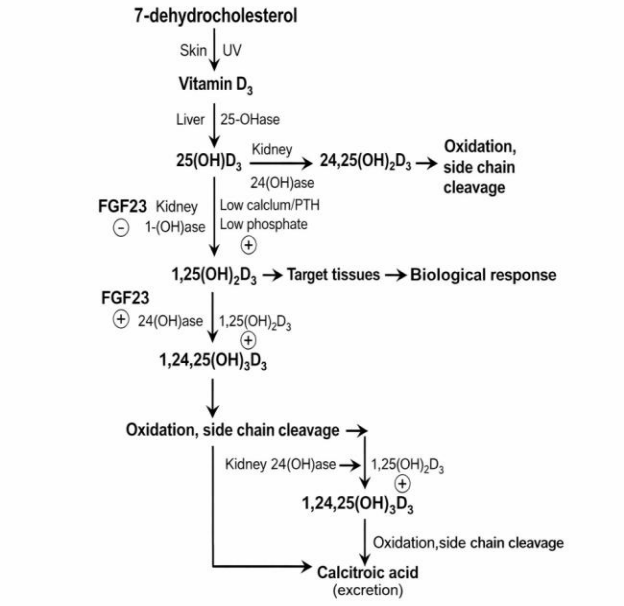

Figure 1: Metabolism of Vitamin D (x)

2.1 Vitamin D Binding Protein (VDBP)

Vitamin D and its metabolites are transported in circulation bound to Vitamin D Binding Protein (VDBP), a hepatically synthesized α-globulin. VDBP demonstrates the highest affinity for 25(OH)D (85–90% of total circulating 25(OH)D is VDBP-bound), followed by 1,25(OH)₂D and unmodified vitamin D itself (xx,lxii). Only ~1% of total vitamin D circulates in its free (bioavailable) form, while albumin binds an additional 10–15%. Beyond transport, VDBP exerts pleiotropic functions: it acts as a macrophage activating factor (DBP-MAF), participates in neutrophil chemotaxis, modulates T cell responses, facilitates endotoxin transport, scavenges extracellular actin released during cell injury, and regulates osteoclast activity and bone resorption (xv,xvi). Following tissue injury, filamentous actin (F-actin) is released into the bloodstream; VDBP binds and neutralizes it, preventing disseminated intravascular coagulation. In liver disease, chronic injury and hepatic protein synthetic dysfunction may alter VDBP levels, indirectly affecting vitamin D bioavailability and transport (lvi,xxxiv).

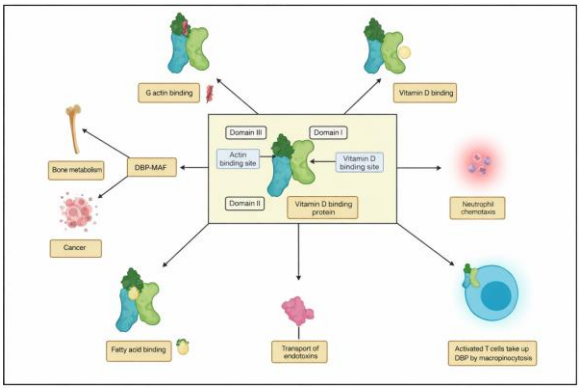

Figure 2: Physiological functions of VDBP (xvi)

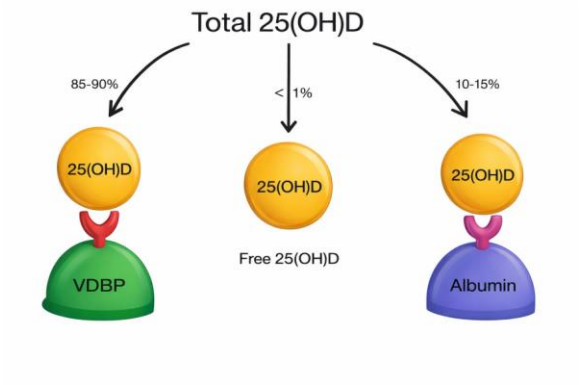

Figure 3: Bioavailability fractions of vitamin D (xx)

2.2 Classical Role: Calcium and Bone Homeostasis

The regulation of calcium and phosphate homeostasis represents the prototypical physiological role of vitamin D. Calcitriol binds to the Vitamin D Receptor (VDR) in intestinal epithelial cells, upregulating the expression of calcium-binding proteins such as calbindin and promoting transcellular calcium absorption (xliv). In bone, vitamin D orchestrates the activity of osteoblasts (bone formation) and osteoclasts (bone resorption), and facilitates collagen matrix mineralization. Deficiency results in rickets

(children) and osteomalacia (adults), characterized by impaired bone mineralization (vii).

2.3 Non-Skeletal (Pleiotropic) Roles of Vitamin D

Beyond mineral homeostasis, vitamin D exerts important immunomodulatory, metabolic, anti-inflammatory, cardiovascular, and anti-neoplastic effects that are increasingly relevant to chronic liver disease and systemic metabolic dysfunction.

2.3.1 Immunomodulation

Vitamin D receptors (VDR) are expressed on a range of immune cells including macrophages, dendritic cells, and T lymphocytes. Through VDR-mediated transcriptional regulation, calcitriol suppresses pro-inflammatory cytokine production (TNF-α, IL-6, IL-1β) while promoting anti-inflammatory IL-10 and regulatory T cell (Treg) differentiation, thus attenuating autoimmune and inflammatory pathologies (xxxii). Vitamin D also reinforces innate immunity by inducing production of antimicrobial peptides such as cathelicidins in macrophages (vi).

2.3.2 Metabolic Regulation and Insulin Sensitivity

Vitamin D plays a significant role in glucose metabolism and insulin sensitivity. Low vitamin D status is consistently associated with insulin resistance, metabolic syndrome, obesity, and type 2 diabetes. Calcitriol enhances insulin receptor signaling, improving glucose uptake in hepatic and skeletal muscle cells (xlviii). Pancreatic β-cells express CYP27B1, enabling local conversion of 25(OH)D to calcitriol, which directly supports insulin synthesis and secretion (xxxix). In animal models, vitamin D deficiency promotes adipose tissue inflammation and increased fat storage (xli).

2.3.3 Anti-inflammatory Effects

Vitamin D's anti-inflammatory properties are particularly relevant in the context of NAFLD. Through VDR-mediated pathways, active vitamin D downregulates pro-inflammatory cytokines (TNF-α, IL-6, IL-1β) and upregulates anti-inflammatory mediators such as IL-10 (xxxix). These effects may attenuate the low-grade chronic inflammation that underpins insulin resistance in NAFLD and metabolic syndrome (xlviii).

2.3.4 Cognitive Function

Emerging evidence associates adequate vitamin D status with preserved cognitive function and a reduced risk of neurodegenerative diseases such as Alzheimer's and Parkinson's disease. VDRs are widely expressed in the brain, and deficiency has been linked to accelerated cognitive decline (v).

2.3.5 Cardiovascular Health

Vitamin D has also been implicated in cardiovascular regulation through its effects on vascular function, inflammation, and blood pressure control. Experimental and observational evidence suggests that vitamin D signaling is relevant to the heart and blood vessels, and low circulating 25-hydroxyvitamin D levels have been associated with an adverse cardiovascular risk profile and increased cardiovascular risk (xlvii). However, although these associations are biologically plausible, randomized clinical trials have generally not demonstrated a consistent reduction in major cardiovascular events with routine vitamin D supplementation, particularly in populations that were not severely deficient at baseline (xlvii,xxxvi). Thus, adequate vitamin D status may contribute to cardiometabolic health, but current evidence does not support vitamin D supplementation solely for cardiovascular disease prevention.

2.3.6 Cancer-Related Actions

Vitamin D has also been investigated for its potential role in cancer prevention and tumor biology. Through VDR-mediated signaling, calcitriol influences key cellular processes including proliferation, differentiation, apoptosis, and angiogenesis, all of which are central to carcinogenesis and tumor progression (xix). Epidemiological evidence has most consistently linked higher circulating vitamin D concentrations with a lower risk of colorectal cancer, although findings for other cancer types remain less consistent (xl). Nevertheless, randomized trials and meta-analyses have not shown a clear reduction in overall cancer incidence with vitamin D supplementation, while any effect on cancer mortality appears modest and still uncertain (xxxvi, xxx). Therefore, although vitamin D remains a biologically plausible anti-neoplastic factor, its role in cancer prevention is not yet definitive.

3. PATHOGENESIS OF FATTY LIVER DISEASE

3.1 Current Understanding: The Multiple Parallel Hits Model

The pathogenesis of NAFLD is now understood within the framework of the 'multiple parallel hits' hypothesis, which supersedes the earlier 'two-hit' model. This paradigm integrates simultaneous insults acting on the liver: (i) gut microbiota dysbiosis promoting endotoxemia and hepatic inflammation; (ii) lipotoxicity from accumulation of toxic lipid intermediates such as ceramides and diacylglycerols; (iii) endoplasmic reticulum (ER) stress contributing to insulin resistance and hepatocyte apoptosis; (iv) mitochondrial dysfunction impairing oxidative phosphorylation, increasing ROS production, and reducing fatty acid β-oxidation; and (v) dysregulated adipokine signaling — reduced adiponectin and increased leptin — promoting insulin resistance and pro-inflammatory hepatic signaling. These converging insults collectively drive hepatic steatosis, progressive inflammation, and fibrogenesis.

3.2 Hepatic Impairment and Vitamin D Metabolism

The liver is the primary site of the first hydroxylation step in vitamin D activation. In NAFLD, hepatic inflammation and fat accumulation impair the expression and activity of CYP2R1 (25-hydroxylase), reducing conversion of vitamin D3 to 25(OH)D independent of dietary intake or sun exposure (xli). The inflammatory milieu in NAFLD may also indirectly suppress renal CYP27B1 (1-α-hydroxylase), further limiting generation of the active calcitriol. Chronic liver disease generally results in low or normal VDBP levels, with variable effects on vitamin D transport and bone metabolism (lvi). Excess actin release during hepatocyte injury may worsen procoagulant status in patients with pre-existing liver damage (xxxiv).

3.3 Role of the Vitamin D Receptor (VDR) in Hepatocytes and Stellate Cells

Vitamin D mediates its cellular effects via the VDR, a nuclear receptor expressed in hepatocytes, HSCs, and hepatic immune cells. In hepatocytes, VDR activation regulates genes involved in lipid metabolism, insulin sensitivity, and bile acid synthesis and detoxification. In HSCs, VDR signaling exerts potent anti-fibrotic effects by inhibiting HSC activation and reducing collagen deposition. VDR expression is dysregulated in NAFLD, and restoration of VDR activity through vitamin D supplementation may represent a mechanistically grounded therapeutic target.

3.4 Inflammation, Insulin Resistance, and Vitamin D

Chronic low-grade inflammation and insulin resistance — cardinal features of metabolic syndrome — disrupt vitamin D metabolic pathways in NAFLD patients. Chronic

inflammation suppresses hepatic 25(OH)D synthesis, while insulin resistance impairs tissue responsiveness to vitamin D. Elevated pro-inflammatory cytokines (TNF-α, IL-6) further compromise VDR signaling, creating a vicious cycle wherein vitamin D insufficiency worsens inflammatory and metabolic disturbances (xlviii).

3.5 Fat Deposition, Adipose Sequestration, and Vitamin D Bioavailability

Excess hepatic and adipose lipid accumulation in NAFLD traps fat-soluble vitamins including vitamin D, reducing circulating bioavailable concentrations (xli). Epidemiological studies consistently demonstrate an inverse correlation between adiposity, NAFLD severity, and serum 25(OH)D levels. Vitamin D modulates adipose tissue function, and hypovitaminosis D has been independently associated with adipose tissue dysfunction — a key driver of NAFLD pathogenesis (xii).

NAFLD encompasses non-alcoholic fatty liver (NAFL) and the more severe NASH (l). In the pediatric population, NAFLD is defined as hepatic steatosis in children ≤18 years not attributable to alcohol, medications, infections, or metabolic/genetic disorders (lxi). Steatosis arises when hepatic fatty acid input (from plasma uptake and de novo lipogenesis) exceeds oxidative output; the resulting intrahepatic triglyceride excess leads to metabolic dysregulation of glucose, fatty acid, and lipoprotein pathways (xxxi).

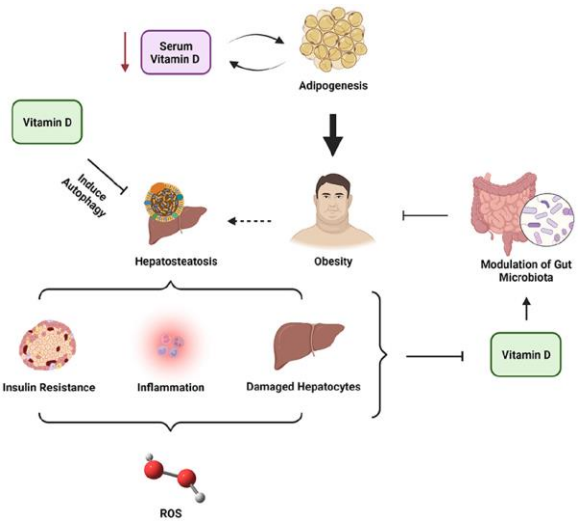

Figure 4: The roles of vitamin D in NAFLD and obesity (xxxvii)

4. VITAMIN D DEFICIENCY AND FATTY LIVER DISEASE

Vitamin D deficiency is consistently observed in patients with chronic liver disease, irrespective of the underlying etiology, and serum vitamin D levels have been shown to correlate inversely with disease severity and the risk of complications (li). Multiple epidemiological studies have established associations between low 25(OH)D concentrations and the development of insulin resistance, metabolic syndrome, and NAFLD (xlix). The co-occurrence of vitamin D insufficiency and obesity — itself a major NAFLD risk factor — suggests interrelated pathophysiological mechanisms (xxii).

Experimental animal studies have demonstrated vitamin D's direct role in regulating oxidative stress, pro-inflammatory cytokine production, hepatocyte apoptosis, and hepatic fibrosis (xxiv). In clinical studies, serum 25(OH)D3 levels have been found to be inversely correlated with NAFLD prevalence and severity. A meta-analysis confirmed that lower vitamin D levels were significantly associated with higher NAFLD prevalence. In a Korean cohort, decreasing

serum 25(OH)D3 tertiles were independently associated with increased NAFLD risk after adjustment for metabolic syndrome (xviii). Further work reinforced the inverse relationship between serum vitamin D and NAFLD. These collective data support the hypothesis that vitamin D deficiency is a contributing factor — not merely a consequence — of NAFLD pathogenesis(xi).

4.1 Prevalence of Vitamin D Deficiency in NAFLD Patients

The clinical importance of vitamin D deficiency in NAFLD becomes clearer when it is viewed against the background prevalence in the wider population. NAFLD itself is highly prevalent, affecting an estimated 32.4% of adults worldwide, which means that even modest metabolic associations may have substantial public-health implications (liii). In the general population, pooled analyses have shown that vitamin D deficiency is already common: one large meta-analysis of population-based studies estimated that 15.7% of individuals had serum 25(OH)D levels below 30 nmol/L and 47.9% had levels below 50 nmol/L globally (xiii).

Against this background, NAFLD-specific meta-analyses suggest a greater burden of hypovitaminosis D among affected patients. In a meta-analysis of 17 observational studies, The study reported that patients with NAFLD were 1.26 times more likely to be vitamin D deficient than controls (xviii). A later systematic review and meta-analysis also found significantly lower circulating 25(OH)D concentrations in individuals with NAFLD than in those without NAFLD, with a pooled mean difference of −16.80 nmol/L (i). Collectively, these findings indicate that vitamin D deficiency is not merely common in the general population, but appears to be overrepresented in NAFLD. However, a single pooled prevalence estimate specifically for NAFLD patients remains difficult to standardize because meta-analyses have largely reported relative odds and mean differences, and the included studies used heterogeneous diagnostic approaches.

5. CLINICAL EVIDENCE ON VITAMIN D SUPPLEMENTATION IN NAFLD

Vitamin D has recognized anti-inflammatory, insulin-sensitizing, and anti-fibrotic actions in experimental systems, which has led to interest in supplementation as an adjunctive therapy for NAFLD. However, the clinical literature remains heterogeneous, with important variation in baseline vitamin D status, NAFLD severity, co-interventions, treatment duration, and outcome measures. As a result, current human evidence supports correction of vitamin D deficiency in affected patients, but does not yet establish vitamin D as a stand-alone disease-modifying treatment for NAFLD or NASH (lvii, iv, lix).

Individual randomized trials have produced mixed findings. In patients with type 2 diabetes and NAFLD, study showed that cholecalciferol at 2,000 IU/day for 24 weeks significantly increased serum 25(OH)D concentrations, but did not improve hepatic fat fraction, transaminases, fibrogenesis markers, metabolic profile, or cardiovascular parameters compared with placebo (iv). Similarly, the study evaluated 50,000 IU/week vitamin D3 and daily calcitriol for 12 weeks in NAFLD and found reductions from baseline in alkaline phosphatase, and in some cases GGT, but no significant between-group advantage over placebo at trial completion. These negative or modest findings indicate that biochemical correction of vitamin D deficiency does not automatically translate into meaningful hepatic improvement (xiv).

Other studies have reported more encouraging signals. In biopsy-proven NASH with hypovitaminosis D, the study found that vitamin D3 at 2,100 IU/day for 48 weeks was well tolerated, significantly

improved ALT, and was associated with a decrease in cytokeratin-18 fragments; however, the study was not powered to detect definitive histological changes. More broadly, some shorter trials using weekly high-dose cholecalciferol have suggested improvements in insulin resistance, inflammatory markers, and selected liver-related indices, especially in patients who were vitamin D deficient at baseline. Nevertheless, these benefits have not been replicated consistently across studies, and the magnitude of effect has varied substantially (xxiii).

5.1 Comparison of supplementation regimens: dose, duration, and formulation

A major reason for inconsistency across studies is the marked heterogeneity of supplementation regimens. Most NAFLD trials have used oral cholecalciferol (vitamin D3), either as lower daily doses such as 2,000–2,100 IU/day or as intermittent high-dose schedules such as 50,000 IU/week. A smaller number have used calcitriol, intramuscular cholecalciferol, or vitamin D given alongside calcium, lifestyle modification, or other nutritional interventions. In the wider chronic liver disease literature, cholecalciferol remains the predominant formulation; calcifediol has been studied only rarely, and ergocalciferol (vitamin D2) is less favored in contemporary guidance. This means that current NAFLD evidence largely reflects vitamin D3-based strategies rather than true head-to-head comparisons between vitamin D2 and vitamin D3 (iv,xiv,xvii).

Taken together, the available data suggest that regimen characteristics may influence outcomes, but no clearly superior protocol has emerged. Lower daily-dose regimens appear sufficient to raise serum 25(OH)D, yet often fail to improve liver fat or fibrosis, whereas higher weekly regimens may show greater effects on HOMA-IR, ALT, or inflammatory markers, though not consistently on steatosis or histology. Co-supplementation studies are especially difficult to interpret because the independent effect of vitamin D cannot always be separated from that of calorie restriction, calcium, omega-3 fatty acids, or other concurrent therapies. Thus, current evidence does not allow a firm conclusion that one dose, duration, or formulation is unequivocally optimal for NAFLD management.

The meta-analytic literature reflects the same mixed picture. A meta-analysis of 10 trials including 544 patients, found significant improvements in fasting glucose, insulin, and HOMA-IR, with only a marginal reduction in ALT and no clear effect on AST or major lipid fractions(xxv). The pooling 16 randomized trials, reported significant improvements in HDL-C, body weight, BMI, waist circumference, ALT, fasting blood sugar, and HOMA-IR(lii). The analysis of seven studies with 735 participants, also found improved HOMA-IR and lower ALT, but no significant effect on AST. These findings suggest that vitamin D supplementation may exert more consistent metabolic than liver-specific benefits, particularly in relation to insulin resistance(lviii).

The most recent synthesis which included 28 interventional studies and 21 randomized controlled trials in steatotic liver disease, reported statistically significant improvements in FibroScan parameters, liver enzymes, insulin resistance, triglycerides, and HDL. However, the authors emphasized that these effects were generally smaller than accepted thresholds for clinical benefit, were inconsistent across analyses, and did not identify any specific subgroup, dose, or duration clearly associated with meaningful therapeutic gain. On balance, vitamin D supplementation appears safe and reasonable for correcting documented deficiency, and it

may modestly improve selected metabolic or biochemical markers, but present evidence does not support its use as a definitive monotherapy for NAFLD. Future trials should stratify patients by baseline vitamin D deficiency, disease severity, and histological stage, and should use standardized dosing schedules and longer follow-up periods to determine whether clinically relevant hepatic benefits can be achieved

Table 1. Summary of Mechanisms Linking Vitamin D to NAFLD and Evidence from Supplementation Studies

Mechanism / Aspect	Role in NAFLD	Effect of Vitamin D
Insulin resistance	Impaired glucose uptake, increased hepatic steatosis	Improves insulin sensitivity via VDR signaling; enhances glucose uptake in muscle and liver (xlviii)
Inflammation	Elevated TNF-α, IL-6, MCP-1; macrophage infiltration	Downregulates pro-inflammatory cytokines; promotes anti-inflammatory Treg cells (xxxii)
Fibrosis	HSC activation, collagen deposition	VDR activation inhibits HSC activation and reduces fibrogenesis (xxiv)
Hepatic CYP2R1 activity	Reduced 25-hydroxylation in NAFLD contributes to low 25(OH)D	Deficiency worsens; supplementation may restore substrate availability (xli)
VDR expression	Altered in hepatocytes and HSCs in NAFLD	VDR activation modulates lipid metabolism, insulin signaling, and anti-fibrotic pathways
Clinical supplementation trials	Variable effects on steatosis and fibrosis; some studies show improvement in ALT, AST, or fibrosis (xliii, xxviii)	Meta-analysis did not show consistent improvement in liver enzymes except for ALP with high doses (>3000 IU/day) (xxxviii)

6. CONCLUSIONS

Vitamin D plays a vital role in maintaining liver health, and emerging research has linked vitamin D deficiency to the development and progression of non-alcoholic fatty liver disease (NAFLD). Its significance in the pathophysiology of NAFLD is underscored by impaired vitamin D metabolism observed in patients, as well as its regulatory role in inflammation, insulin sensitivity, and hepatic lipid metabolism. Clinical studies suggest that vitamin D supplementation may offer a promising therapeutic strategy to reduce inflammatory responses and metabolic disturbances associated with NAFLD, potentially slowing disease progression and improving patient outcomes. However, findings remain inconsistent across studies. Therefore, further research is needed to fully elucidate the mechanisms by which vitamin D influences

liver function and to determine optimal dosing and treatment protocols for NAFLD patients. Given the rising global prevalence of NAFLD, a clearer understanding of vitamin D's role in its management could support the development of effective, evidence-based interventions to improve patient quality of life.

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