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Progressive Worsening of Vitamin D Deficiency Is Associated With Adverse Clinical Outcomes in Surgical Intensive Care Unit Patients

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Abstract

General Background: Vitamin D deficiency is recognized as a major nutritional disorder associated with immune dysregulation, prolonged hospitalization, and increased mortality in critically ill populations. **Specific Background:** Surgical intensive care unit (SICU) patients are particularly vulnerable to hypovitaminosis D because of severe physiological stress, limited nutritional intake, and reduced sunlight exposure during hospitalization. **Knowledge Gap:** Despite increasing evidence linking vitamin D deficiency with adverse outcomes, limited prospective data are available regarding the severity distribution and prognostic significance of vitamin D deficiency among surgical ICU patients in Iraq. **Aims:** This study evaluated the prevalence of vitamin D deficiency and its association with clinical outcomes among SICU patients admitted to Ghazi AL Hariri Hospital for Surgical Specialties, Baghdad. **Results:** A prospective cohort study involving 240 SICU patients demonstrated that severe vitamin D deficiency was present in 53.5% of participants, while only 1.2% had normal vitamin D status. Severe deficiency was associated with prolonged SICU stay, increased treatment costs, and higher mortality rates. Patients with severe deficiency showed a mean SICU stay of 15.33 days, significantly longer than those with moderate or mild deficiency (P = 0.002). Multivariate analysis confirmed vitamin D deficiency as an independent predictor of adverse clinical outcomes. **Novelty:** The study introduces severity-based vitamin D classification in SICU patients and demonstrates its prognostic relevance in a critically ill surgical population. **Implications:** Early screening and correction of vitamin D deficiency may support risk stratification and clinical management strategies in surgical intensive care settings.

Highlights:

- Severe hypovitaminosis D predominated among critically ill surgical patients admitted to SICU.
- Longer intensive care hospitalization was identified in patients with profound nutrient depletion.
- Mortality and treatment expenditure increased across lower serum 25-hydroxyvitamin D categories.

Keywords: Vitamin D Deficiency, Surgical Intensive Care Unit, Critical Illness, Mortality, Serum 25 Hydroxyvitamin D

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Introduction

Vitamin D deficiency constitutes the most prevalent nutritional deficiency in the United States, afflicting more than 70% of the general population [1] , [2] , [3] .

Etiological Factors

A multitude of dietary, physiological, environmental, and behavioral factors precipitate this deficiency. Key contributors include the paucity of vitamin D in unfortified foods, as very few dietary staples are enriched with this nutrient; the application of sunscreen, which occludes 95% of dermal vitamin D synthesis; elevated melanin pigmentation in individuals of African American descent, who require 3- to 6-fold longer sun exposure than Caucasians to generate equivalent vitamin D quantities; 1-age-related declines in cutaneous production, with elderly skin (at age 70) exhibiting a 70% reduction in synthetic capacity;2- obesity, whereby vitamin D becomes sequestered in adipocytes rather than circulating freely or storing in the liver as in normal weight individuals; 3- chronic kidney disease; 4- hepatic failure; 5- indoor lifestyles (e.g., among nursing home residents); inadequate supplementation, as current recommended daily allowances prove insufficient for optimal health; and variations attributable to season, latitude, and time of day. [1]

Geophysical Modalities on Endogenous Synthesis

Endogenous vitamin D production hinges on ultraviolet B (UVB) radiation within the 290–315 nm wavelength band, which drives the photo conversion of 7-dehydrocholesterol to pre-vitamin D3 in the epidermis. Winter sunlight impinges at oblique angles of approximately 45° on the northern hemisphere, in contrast to the near-perpendicular 90° incidence of summer that optimally delivers requisite UVB during peak midday hours (10:00 AM to 3:00 PM). [4] Although vitamin D is classified as one of fat-soluble vitamins with a primary role in calcium homeostasis and bone metabolism, it is now well established that vitamin D also functions as a steroid hormone with wide-ranging pleiotropic effects. [2] Vitamin D is obtained through two principal sources: a-endogenous synthesis in the skin following exposure to ultraviolet B radiation .b- exogenous intake from dietary sources and supplements. Following its production or ingestion, vitamin D undergoes hepatic metabolism to form 25-hydroxyvitamin D [25-(OH)D], which represents the predominant circulating form and is widely accepted as the most reliable biochemical marker for assessing an individual's vitamin D status. [1] .Subsequently, 25-(OH)D_3 is further hydroxylated in the kidney by the enzyme 25-hydroxyvitamin D-1α-hydroxylase, resulting in the formation of 1,25-dihydroxyvitamin D_3 [1,25-$(OH)_2D_3$], the biologically active form of the hormone. [1] This active metabolite mediates its biological effects through interaction with the vitamin D receptor (VDR), a nuclear receptor involved in the regulation of gene transcription.. Recent evidence has demonstrated that VDRs are expressed in nearly all human tissues and cell types, indicating that vitamin D has systemic effects extending far beyond skeletal health. Apart from its well-recognized role in phosphate , calcium , magnesium homeostasis and bone formation, vitamin D has been shown to play a critical role in immunomodulation, including both innate and adaptive immune responses. Several studies have highlighted its involvement in the regulation of inflammatory processes and cytokine production, as well as its influence on cellular proliferation, differentiation, apoptosis, and angiogenesis. [1] , [2] .Furthermore, vitamin D has been implicated in maintaining muscle function, contributing to muscle strength and contraction, and may therefore play a role in overall physical performance and recovery. Collectively, these findings underscore the multifaceted biological actions of vitamin D and support the growing recognition of its importance in a wide range of physiological and pathological processes beyond bone metabolism. [1] , [2] . Epidemiological research has established significant associations between vitamin D deficiency and a broad spectrum of adverse health outcomes. Substantial evidence links of insufficient level of vitamin D to the pathogenesis of cardiovascular diseases, various autoimmune diseases , and an increased risk for at least seventeen distinct malignancies, including cancers of the breast, prostate, lung, colon, and kidney. These conditions are further correlated with elevated mortality rates [1] , [5] , [6] . This association with mortality is supported by a meta-analysis encompassing eighteen randomized clinical trials, which concluded that randomization to vitamin D supplementation was linked to a reducing mortality within the population [6] . While the synergistic role of vitamin D and calcium in preserving bone mineral density with advancing age is well-documented, vitamin D insufficiency is also posited as an separated risk factor for falls and osteoporotic fractures in elderly cohorts [5] , [7] . The clinical significance of this deficiency is underscored by findings indicating that serum 25-hydroxyvitamin D levels below 17.8 ng/mL elevate the risk of all-cause mortality by 26% in the general populace [5] ,[7] .

Despite the compelling nature of these observational data, a significant gap persists in the translation of this evidence into definitive clinical practice guidelines. There remains a paucity of high-quality evidence to inform clinicians on appropriate screening protocols for vitamin D deficiency or to establish standardized, effective treatment regimens. This evidence deficit is particularly acute within specific high-risk patient populations, such as those sustaining traumatic injury or critically ill surgical patients requiring intensive care unit (ICU) admission, where the impact of deficiency and the benefits of repletion are not fully characterized [8] , [9] . Consequently, evidence-based methods for the management of vitamin D disorder status in these vulnerable groups represents a critical area for future clinical investigation.

Methods

A prospective observational investigation was carried out involving 240 individuals under trauma, vascular, and general surgical care, who were received into the critical care ward for surgical patients at GHazi AL Hariri Hospital for Surgical Specialties, located within the Medical City complex in Baghdad, Iraq. The research period extended from August 2019 through January 2021. Its objective was to evaluate the frequency of insufficient vitamin D levels and its association with unfavorable clinical developments within this group.

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All individuals entering the critical care ward were involved in this investigation was with no restrictions on participation. Measurements of serum vitamin D concentrations were obtained for every subject within the first day following their arrival in the critical care unit, utilizing the analytical technique of high-pressure liquid chromatography-tandem mass spectrometry. In light of the widespread international prevalence of vitamin D insufficiency, and given that addressing detected nutritional shortfalls is a standard aspect of managing these vulnerable patients, permission for conventional vitamin D supplementation was integrated into routine clinical practice. This investigation aimed to ascertain if a more intensive approach to rectifying vitamin D insufficiency affects patient results and to determine if such a deficiency constitutes an independent prognostic indicator rather than merely a sign of overall poor health. Among the 240 treated participants, no negative incidents, such as instances of elevated blood calcium, were documented.

To better characterize deficiency severity, a vitamin D–deficiency severity scale was developed and defined as follows: 1- severe deficiency, <13 ng/mL; 2-moderate deficiency, 14–26 ng/mL; 3- mild deficiency, 27–39 ng/mL; and 4- normal vitamin D status, >40 ng/mL (Table 1). The majority of current understanding regarding vitamin D physiology and clinical significance has been established within the past decade. Based on emerging clinical and physiological evidence, we determined that a revised classification system was warranted. Clinically, it was noted that the majority of fatalities arose when circulating vitamin D concentrations fell under 13 ng/mL, marking the initial critical threshold. Additionally, no mortality was recorded in cases where vitamin D measures surpassed 26 ng/mL. Following established hospital protocols that require vigorous replenishment of nutrient shortfalls in severely ill individuals, all participants began receiving vitamin D augmentation (weekly doses of 50,000 IU) once they could sustain tube or oral feeding. Subsequent assessments of vitamin D were not regularly conducted, as existing specialist recommendations note that roughly twelve weeks of intensive weekly administration is necessary to achieve sufficient stable levels in deficient persons. Consequently, this intervention strategy did not immediately impact the investigation's endpoint variables or introduce bias into the findings. The management rationale is supported by contemporary data indicating that restoring dietary insufficiencies is crucial for enhancing recuperation and health endpoints in critically ill patients experiencing physiological strain. Additionally, newer studies reveal that muscular power, speed of movement, and bone density keep progressing till blood concentrations of 25-hydroxyvitamin D arrive at or surpass 40 ng/mL. Furthermore, vitamin D quantities commonly decrease by 20%–30% throughout colder seasons in moderate climate zones. Thus, setting an initial cutoff of 30 ng/mL or less does not deliver ideal defense for the immune system during these intervals of comparative vitamin D shortage. We examined initial participant characteristics (years since birth, ethnic background, gender) and dietary condition using blood measurements of calcium, albumin, and transthyretin. To gauge the effect of coexisting medical conditions, we recorded instances of heart conditions, lung infection, bladder infection, lung blood clot, cancerous growth, and physical trauma. The principal endpoints were the duration of stay in the postoperative critical care unit and corresponding expenses. The additional endpoint was the fatality proportion within vitamin D-insufficient groups. A probability value below 0.05 was considered indicative of statistical relevance

Results

Among the 240 patients evaluated, 70.2% (n = 170) were male and 29.8% (n = 70) were female. Severe vitamin D deficiency was present in 129 patients (53.5%), moderate deficiency in 91 patients (38.4%), mild deficiency in 17 patients (6.9%), and normal vitamin D levels in 3 patients (1.2%). Trauma patients accounted for 85.8% (n = 206) of admissions. During the intensive care unit (ICU) stay, pneumonia developed in 21.6% (n = 52) of patients, and 35.4% (n = 85) required endotracheal intubation. Baseline patient characteristics are summarized in Table 2. Mean serum vitamin D concentrations were 8.25 ng/mL in the severely deficient group, 18.74 ng/mL in the moderately deficient group, and 30.5 ng/mL in the mildly deficient group. The mean length of stay in the surgical intensive care unit was significantly longer in patients with severe vitamin D deficiency compared with those with moderate and mild deficiency, as shown in Table 3.

Table 1: Matthews-Danner-Ahmed Vitamin D scale

scale	Lower level, ng/mL	Upper level, ng/mL
Normal level	More than 40	Less than 70
Mild reduction	(27)	(39)
Moderate reduction	(14)	(26)
Severe reduction	≤ 4	≤13

Groups of normal level and mild one of vitamin deficiency experienced same results regarding surgical intensive care unit (SICU) stays, while the severe deficiency group had a significantly longer mean stay compared to the moderate and mild groups (P = .002). Mortality was significantly higher in the combined severe and moderate group versus the others (P = .047), though not between severe and moderate deficiency alone (P < .199).

Table 2 : characteristics of Baseline population

Characteristics		Frequency, n	Percentage
gender		170 male	70.2 %
		70 femal	29.8 %
vitamin D deficiency	Severe (≤13 ng/mL)	129	53.5%

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	Moderate (14–26 ng/mL)	91	37.2%
	Mild (27–39 ng/mL)	17	7.0%
	Normal (≥40 ng/mL)	3	1.2%
TRAUMA		206	85.8%
INTUBATED		85	35.4%
PNEUMONIA		52	21.6%
COMORBIDITY		44	18.3%
MORTALITY		28	11.6%

Table 3: group description of Vitamin D–deficiency

Variable	Severe group percent	Moderate group percent	Mild group percent
Pre-albumin level, mg/dL	45.8%	36.2%	18%
Albumin level, mg/dL	51.6%	41.32%	7.08%
Calcium level, mg/dL	51.6%	36.05%	12.35%
Vitamin D level, ng/mL	57.5%	35%	7.5%
Length of ICU stay	54.5%	38.0%	7.5%

Discussion

Deficiency in vitamin D represents a widespread global health concern in modern societies. [1] A link between insufficient vitamin D levels and elevated overall death rates among the general public is firmly supported by evidence. [5] [7] , [9] Many specialists propose that sustaining optimal vitamin D concentrations could lower the probability of developing numerous chronic conditions associated with aging. [6], [10], Importantly, a recent long-term investigation found that subjects with a vitamin D deficiency faced nearly double the likelihood of dying during a seven-year observation window relative to participants with stable, normal vitamin D concentrations in their blood. [5] Studies indicate that over half of all patients in critical condition upon admission to intensive treatment facilities present with this deficiency

[9], [8] Prior investigations applying established benchmarks probably failed to capture the full extent and clinical impact of insufficiency in this high-risk group. To address this shortcoming, this analysis aimed to precisely measure the frequency of low vitamin D levels in surgical critical care admissions, without exclusion based on diagnosis. There remains significant disagreement and inconsistency in the blood level cutoffs used to categorize optimal, suboptimal, and inadequate vitamin D concentrations. [11], [12] Traditionally, blood concentrations of 25-hydroxyvitamin D [25(OH)D] under 5–7 ng/mL have correlated with classic bone-softening diseases, whereas measurements under 10–12 ng/mL have been connected to elevated parathyroid hormone and reduced bone mass. [1] , [12] Values above 18–20 ng/mL were once considered sufficient, but these standards primarily aimed to avoid clear skeletal disorders, not to promote peak physiological function. Contemporary data indicates a strong, uninterrupted correlation between serum 25(OH)D3 quantities and bone density measurements among diverse populations [6] , [10] , [13] , [14] Maximal bone mineral density was achieved only when serum 25(OH)D levels reached or exceeded 40 ng/ mL. [1] , [15] [16] In addition, intestinal calcium absorption declines significantly when 25(OH)D levels fall to 30 ng/mL or lower. [12] Studies further indicate that suppression of parathyroid hormone secretion and attainment of maximal bone mineral density at the hip and lumbar spine require serum 25(OH)D concentrations of approximately 40 ng/ mL. [1], [11] , [17] Accordingly, we selected 40 ng/mL [18] as the lower threshold for normal vitamin D status in this study. These revised cut-off values suggest that earlier classifications of “normal” serum 25(OH)D levels may have relied on an inadequate statistical and clinical framework, particularly when the goal is to maintain optimal physiological function and reduce disease risk rather than merely prevent severe deficiency states. [12] , [19] , [20] .This perspective may hold particular importance for patients with severe illness, where even minor disruptions in normal body function can lead to significant health impacts. As a further goal, we aimed to categorize individuals into four equal groups based on the extent of their low vitamin D status, assessing how health measures and results differed across these categories. Laboratory testing of specimens was conducted off-site, leading to a reporting lag of 7–14 days; thus, concentrations of serum 25-hydroxyvitamin D [25-(OH)D] were unknown upon hospital entry and played no role in determining treatment strategies or care plans. The link between insufficient vitamin D and long-term disease is extensively established. It is reasonable to suggest that vitamin D concentrations may steadily decrease during a postoperative critical care admission, due to minimal exposure to natural light and insufficient nourishment, potentially accounting in part for the greater likelihood of death noted in severely unwell individuals under intensive treatment. [8], [9] . Those entering the surgical intensive therapy environment are recognized to experience greater rates of nosocomial infections, severe lung injury, and failure of multiple organ systems. Conventionally, the elevated potential for poor results in this group has been linked to septic events and suboptimal nourishment, indicated by reduced serum albumin or transthyretin concentrations prior to hospital stay, considerable reduction in body mass (≥10%), and underlying persistent health issues. Nonetheless, we propose that the greater likelihood of death associated with intensive care is directly linked to both the existence and the

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extent of vitamin D insufficiency. Growing data from various research teams, such as Liu and colleagues, [21] Jeng and associates, [22] and Baeke et al, [23], [24] reveals that vitamin D has diverse immune-altering properties and could potentially act as a key controlling agent for the body's defense system

Emerging research demonstrates that vitamin D influences cellular defenses across the immune system [1]. For innate immunity, it enhances production of certain antimicrobial agents, such as cathelicidin [1] and β-defensins [1] , [23] , [24] , generated by key white blood cells. Moreover, the active hormonal form synthesized in tissues reduces levels of numerous proinflammatory signaling molecules—like interleukin (IL)-1, IL-2, interferon-γ, tumor necrosis factor-α, IL-6, IL-8, and IL-12—while also lessening the function of specific helper T cells and antibody-producing B cells belonging to the adaptive immune branch [1] , [23] , [24] . Effective tissue-level generation of this hormonal vitamin D derivative depends on circulating precursor concentrations exceeding approximately 30–40 ng/mL (or >75–100 nmol/L) [1] [17] . Therefore, people with suboptimal levels might display a weakened reaction to physical stressors, trauma, or pathogens. This concept provides a reasonable rationale for the increased death rates documented in groups with profound insufficiency relative to those with milder deficits. Apart from its well-established part in mineral balance and parathyroid function, growing data imply that vitamin D carries out wider physiological roles through its specific cellular receptor [1] , [2] . Some actions seem to occur without involving parathyroid mechanisms. Nevertheless, in particular disease settings, a detrimental feedback loop can emerge where low active hormone concentrations worsen inflammation and kidney dysfunction, a condition often resistant to conventional replacement therapy [25], [26] . These findings clarify the links connecting insufficient vitamin D status with higher fatalities in both community and hospitalized cohorts [1] , [21], since such individuals possibly lack sufficient capacity to generate an appropriate protective reaction

adequate physiological and immunological response to tissue injury and infection, they tend to experience prolonged stays in the intensive care unit as a consequence of persistent systemic inflammatory response syndrome (SIRS) and are more likely require extended durations of mechanical ventilation. Although the difference in surgical intensive care unit (SICU) length of stay between the severely deficient group and the mildly to moderately deficient groups did not reach statistical significance, the additional 7–8 mean days observed were nonetheless of clear clinical and economic relevance. Moreover, accumulating evidence from observational investigations and a meta-analysis of randomized controlled trials suggests that elevated circulating levels of 25-hydroxyvitamin D [25(OH)D], as well as supplementation with either vitamin D_2 (ergocalciferol) or vitamin D_3 (cholecalciferol) at an average daily intake of approximately 528 IU, may be associated with a reduction in all-cause mortality [1] . Given that a substantial proportion of trauma patients originate from the general community, routine screening for vitamin D deficiency should be emphasized and deficiency recognized as an independent contributor to adverse clinical outcomes, including increased morbidity and mortality, in patients requiring admission to the surgical intensive care unit. Accordingly, correction of vitamin D deficiency warrants attention in both ambulatory care and hospital-based settings. The biological functions of vitamin D extend far beyond its classical involvement in calcium and phosphate regulation. Vitamin D status plays a critical role in immune homeostasis by influencing both innate and adaptive immune mechanisms [25] . Modulation of these immune pathways represents a complex balance, as vitamin D–mediated effects may yield both protective and potentially detrimental consequences depending on the clinical context [23] . For instance, attenuation of adaptive immune responses may be beneficial in autoimmune or inflammatory disorders; however, such immunosuppression may simultaneously predispose critically ill patients to infectious complications, which are

particularly prevalent in the ICU environment [26]. In contrast, stimulation of innate immunity enhances host defense against pathogens such as Mycobacterium tuberculosis, yet excessive activation of pro-inflammatory pathways may contribute to collateral tissue injury, including bone demineralization associated with pneumonia, sepsis, and prolonged immobilization—frequent conditions in severely injured or critically ill individuals [26] .

Collectively, existing data indicate that adequate vitamin D status supports effective immune defense against infection [1] . [26] . Beyond its well-known importance in maintaining bone integrity, vitamin D is involved in numerous physiological functions throughout the body encompassing antimicrobial protection, oncologic risk modulation, skeletal muscle function, and cardiovascular support, including potential benefits in congestive heart failure [27]. Importantly, emerging evidence highlights the anti-inflammatory actions of vitamin D, which may help mitigate the dysregulated inflammatory response characteristic of bacterial sepsis in surgical ICU populations [28]. Profound vitamin D deficiency may compromise immune regulation by impairing the appropriate suppression of adaptive immune responses and disrupting innate immune control, thereby providing a plausible mechanistic link to the increased mortality observed in patients with moderate to severe deficiency. These findings underscore the need for more proactive strategies aimed at primary prevention and early correction of vitamin D deficiency in high-risk populations. Outpatient settings and secondary intervention upon hospital and ICU admission are warranted to mitigate the adverse outcomes associated with suboptimal level of vitamin D [15] . insufficient Vitamin D frequently observed in patients requiring admission to ICU [1] , [9]. Growing evidence suggests that low vitamin D status may influence outcomes in both infectious and noninfectious forms of critical illness; however, the extent to which differing concentrations of vitamin D affect prognosis across various ICU admission diagnoses remains incompletely defined. Data from a recent French cohort study confirmed the high prevalence of vitamin D deficiency at the time of ICU admission and highlighted a subset of patients with modifiable determinants contributing to reduced availability of the biologically active form of vitamin D[29] . The development of hypovitaminosis D is attributable to multiple factors, including inadequate exposure to ultraviolet radiation before and during prolonged illness, insufficient nutritional intake, and disease-related disturbances in vitamin D metabolism and parathyroid hormone regulation. In light of these observations, increased clinical awareness is warranted to identify occult vitamin D deficiency among vulnerable ICU populations, and prompt consideration should be given to initiating vitamin D replacement therapy.

Conclusions

Deficiency of vitamin D at moderate to severe levels is associated with prolonged surgical intensive care unit stays, elevated costs related to ICU management, and increased mortality. These findings support the incorporation of vitamin D status

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evaluation at the time of surgical ICU admission, with early therapeutic intervention considered for patients whose serum level of vitamin D concentrations fall below 40 ng/mL. Additional prospective studies are necessary to establish evidence-based screening criteria, determine optimal supplementation protocols, and define appropriate dosing strategies for addressing vitamin D deficiency as a modifiable contributor to adverse outcomes in SICU .

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