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THE IMPACT OF VITAMIN D3 LEVELS ON RECOVERY AND REHABILITATION FOLLOWING SURGICAL TREATMENT OF FEMORAL NECK FRACTURES: A NARRATIVE REVIEW

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ABSTRACT

Introduction and purpose: Femoral neck fractures are a major source of morbidity and mortality among older adults, frequently leading to prolonged hospitalization, disability, and loss of independence. Vitamin D3 plays a central role in bone metabolism, muscle function, and immune modulation- all crucial for postoperative recovery. However, the clinical relevance of vitamin D3 status in patients undergoing surgery for femoral neck fractures remains incompletely understood. This narrative review aims to synthesize current evidence on the relationship between vitamin D3 levels and key outcomes including functional recovery, complication rates, and mortality in this population.
Material and method: A comprehensive literature search was conducted in PubMed and Embase using Boolean operators and relevant medical subject terms. Filters limited the search to full-text, English-language studies published between 2020 and 2025 involving human subjects. In Embase, only randomized controlled trials and systematic reviews were included. A total of 98 non-duplicate studies were screened; 34 were selected for full-text analysis and thematic synthesis.
Results: Most studies demonstrate a positive association between sufficient 25(OH)D levels and faster mobility recovery, improved functional scores (e.g., Harris Hip Score, Barthel Index), and better postoperative quality of life. Vitamin D3 deficiency is consistently linked to higher rates of infectious complications, delayed fracture healing, and increased fall risk. Several studies also associate low 25(OH)D levels with elevated short-term mortality. Supplementation strategies appear beneficial, although optimal dosing and timing remain under debate.
Conclusions: Vitamin D3 status is a potentially modifiable factor influencing outcomes after femoral neck fracture surgery. Routine screening and appropriate supplementation should be considered as part of multidisciplinary perioperative care. Further randomized trials are needed to define causal relationships and refine clinical protocols.

KEYWORDS

Vitamin D3, Femoral Neck Fracture, Hip Fracture, Fracture Healing, Postoperative Recovery, Supplementation

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1. Introduction

1.1 Epidemiology of Femoral Neck Fractures

Femoral neck fractures represent a major global health concern, particularly in the aging population. As the demographic shift toward increased life expectancy accelerates, the incidence of these injuries continues to rise. Globally, over 1.3 million hip fractures occur annually, and this number is projected to exceed 6 million by 2050 [1–3]. Femoral neck fractures constitute a significant proportion of these injuries, especially among individuals over the age of 65, where osteoporosis and frailty are major contributing factors [4,5].

These fractures are associated with considerable morbidity, loss of independence, and increased mortality rates. Studies estimate that up to 30% of patients die within the first year following a hip fracture, and more than half fail to regain their pre-fracture level of mobility or autonomy [6–8]. The burden is not only clinical but also economic; the cost of managing hip fractures, including surgical treatment and prolonged rehabilitation, places a heavy strain on healthcare systems worldwide [9,10].

Due to their frequency, consequences, and resource implications, femoral neck fractures are a critical focus of geriatric and orthopaedic care. Understanding modifiable risk factors such as nutritional status and bone health, including vitamin D levels is essential for improving outcomes in this vulnerable patient population [11,12].

1.2 Role of Vitamin D3 in the Musculoskeletal System

Vitamin D3 (cholecalciferol) plays a central role in maintaining musculoskeletal health through its effects on calcium-phosphate homeostasis, bone remodelling, and muscle function. It is synthesized endogenously in the skin under ultraviolet B (UVB) radiation and undergoes hepatic and renal hydroxylation to become the biologically active form, calcitriol (1,25-dihydroxyvitamin D)[2,13].

In the skeletal system, vitamin D3 promotes intestinal absorption of calcium and phosphorus, stimulates osteoblast differentiation, and regulates bone turnover through its actions on the RANK/RANKL/OPG axis [14,15]. In the absence of sufficient vitamin D, secondary hyperparathyroidism develops, leading to bone resorption and impaired mineralization- key mechanisms underlying osteoporosis and fracture susceptibility [7,16].

Beyond its role in bone physiology, vitamin D3 is also essential for neuromuscular coordination and muscle strength. Its deficiency has been linked to proximal muscle weakness, postural instability, and increased risk of falls in older adults- all of which are major contributors to fracture risk and impaired recovery [6,10,17].

The multifaceted role of vitamin D3 in bone and muscle biology positions it as a potentially modifiable factor in both the prevention and rehabilitation phases of femoral neck fractures [9,18,19].

1.3 Rationale for This Review

Despite the well-established physiological roles of vitamin D3 in skeletal and neuromuscular systems, its clinical significance in the postoperative recovery of patients with femoral neck fractures remains incompletely understood. While some studies suggest that low serum 25(OH)D levels are associated with prolonged rehabilitation, increased complication rates, and higher mortality, others report inconsistent or non-significant findings [3,18,20,21].

The heterogeneity in study design, population characteristics, baseline vitamin D status, supplementation protocols, and outcome measures has contributed to these discrepancies [5,9,22]. Furthermore, while randomized controlled trials and systematic reviews exist, their findings are not always congruent, and few directly target the specific population of surgically treated femoral neck fracture patients.

Femoral neck fractures predominantly affect older adults- a population in which vitamin D deficiency is both common and often underdiagnosed. This demographic overlap raises clinically important questions about whether optimizing vitamin D status can improve recovery trajectories following surgery. Considering the substantial global burden of these fractures and the critical importance of regaining function after operative treatment, there is a clear need to synthesize and contextualize the existing evidence. A targeted, thematically structured review of studies addressing the relationship between vitamin D3 levels and postoperative outcomes in this population is both timely and clinically meaningful [4,23,24].

1.4 Aim of the Study

The aim of this narrative review is to synthesize current evidence regarding the association between serum vitamin D3 levels and clinical outcomes in patients undergoing surgical treatment for femoral neck fractures. The review explores the impact of vitamin D3 status on postoperative recovery, including functional outcomes, complication rates, and mortality.

In addition, the review examines the role of vitamin D3 supplementation as a potential modifiable factor influencing rehabilitation success and overall prognosis. By organizing findings thematically, this work aims to provide clinicians with a clearer understanding of the relevance of vitamin D3 in this specific orthopedic context and to inform evidence-based postoperative care strategies.

2. Methods

This narrative review was conducted in accordance with principles of evidence-based medicine, aiming to synthesize recent clinical findings on the relationship between vitamin D3 levels and postoperative outcomes in patients with femoral neck fractures. A structured literature search was performed using two major biomedical databases: PubMed and Embase. The search strategy was formulated using Boolean operators and controlled vocabulary terms, where applicable.

The following search query was applied:

("Vitamin D" OR "Vitamin D3" OR "cholecalciferol" OR "25-hydroxyvitamin D" OR "25(OH)D") AND ("Hip Fractures" OR "Femoral Neck Fractures" OR "femoral neck fracture" OR "hip fracture") AND ("Recovery of Function" OR "recovery" OR "rehabilitation" OR "functional outcome" OR "healing" OR "postoperative complications" OR "mobility" OR "mortality").

Filters were applied to restrict the search to studies:

(1) published between January 2020 and July 2025,
(2) available in full text,
(3) written in English, and
(4) involving human subjects.

In PubMed, this yielded 51 articles. In Embase, the search was further refined by limiting results to randomized controlled trials (RCTs) and systematic reviews, which returned 53 studies. After removing duplicates, a total of 98 unique records were identified for initial screening. Titles and abstracts were reviewed for relevance to the topic, leading to the selection of 36 studies for full-text assessment. Two studies were excluded after full-text review, resulting in a final dataset of 34 articles included in the synthesis.

Studies were included if they addressed one or more of the following: the association between serum vitamin D3 (or 25(OH)D) levels and postoperative outcomes (e.g., mobility, function, complications, mortality), or the effect of vitamin D3 supplementation in patients undergoing surgical treatment for femoral neck fractures. Both interventional and observational studies were eligible, provided they focused on adult populations and contained extractable clinical outcomes relevant to postoperative recovery.

Data from the included studies were extracted manually and analyzed thematically to identify recurring patterns, divergent findings, and clinically relevant implications. No formal meta-analysis was performed due to heterogeneity in study design, outcome measures, and supplementation protocols.

3. Pathophysiological Role of Vitamin D3 in Fracture Healing

3.1 Synthesis and Metabolism of Vitamin D3

Vitamin D3 (cholecalciferol) is primarily synthesized in the skin through ultraviolet B (UVB) radiation–induced conversion of 7-dehydrocholesterol. It is then hydroxylated in the liver to form 25-hydroxyvitamin D [25(OH)D], the main circulating form and clinical marker of vitamin D status. A second hydroxylation occurs in the kidneys, producing the biologically active 1,25-dihydroxyvitamin D (calcitriol), which exerts endocrine functions on multiple tissues [2,13,14]. Minor amounts of vitamin D3 are obtained through dietary intake, primarily from fatty fish, fortified dairy products, and supplements.

3.2 Role of Vitamin D3 in Bone and Muscle Metabolism

Vitamin D3 plays a central role in calcium-phosphate homeostasis and bone remodelling. It enhances intestinal absorption of calcium and phosphorus, facilitates mineral deposition, and regulates osteoblastic and osteoclastic activity through modulation of the RANK/RANKL/OPG pathway [4,15,25]. In skeletal muscle, vitamin D3 contributes to mitochondrial function, type II muscle fibre maintenance, and neuromuscular coordination [6,8,10]. These actions are crucial not only for bone strength but also for balance and fall prevention in elderly individuals.

3.3 Effects of Vitamin D3 Deficiency on Fracture Healing and Muscle Strength

Deficiency of vitamin D3 leads to impaired bone healing via multiple mechanisms, including secondary hyperparathyroidism, increased bone resorption, and defective callus formation [9,11,16]. Low serum 25(OH)D has been associated with reduced osteoblast activity and delayed endochondral ossification in both experimental and clinical studies [3,17,19]. Additionally, vitamin D deficiency contributes to proximal muscle weakness, reduced functional capacity, and greater risk of falls- all of which may hinder postoperative rehabilitation following femoral neck fracture [8,26,27].

4. Clinical evidence- Thematic Synthesis from the Literature

4.1 Vitamin D3 Status and Functional Recovery

4.1.1 Time to Regain Ambulation/ Mobility

Several observational studies have suggested that lower preoperative serum 25(OH)D levels are associated with delayed recovery of ambulation following surgical repair of femoral neck fractures. Patients with vitamin D deficiency were more likely to remain non-weight bearing or require walking aids for extended periods after surgery [2,3,12]. In contrast, individuals with adequate vitamin D status demonstrated faster achievement of independent walking and earlier return to baseline mobility levels [4,28].

One prospective cohort study found that patients with 25(OH)D levels >30 ng/mL regained unaided ambulation significantly faster (median 21 days vs. 35 days; $p < 0.01$) compared to those with deficient levels [11]. Similar findings were echoed in smaller trials where pre-fracture vitamin D sufficiency correlated with shorter rehabilitation stays and faster discharge from inpatient rehabilitation settings [18,21].

4.1.2 Functional Outcome Scores

Functional recovery has also been assessed using standardized tools such as the Harris Hip Score (HHS), Barthel Index, and Timed Up and Go (TUG) test. Studies consistently report that patients with sufficient or supplemented vitamin D3 levels achieve higher scores on these scales postoperatively [6,7,20].

For instance, a randomized controlled trial demonstrated a statistically significant improvement in 6-month HHS among patients who received high-dose cholecalciferol perioperatively compared to placebo (83.4 ± 5.6 vs. 76.1 ± 6.9, $p < 0.01$) [19]. In addition, Barthel Index scores measuring activities of daily living were higher in patients with normalized vitamin D levels at discharge [9,29].

4.1.3 Postoperative Quality of Life (QoL)

Quality of life, as assessed by instruments such as the Short Form Health Survey (SF-36) and EQ-5D, has been shown to correlate with serum vitamin D3 status in the postoperative period. Patients with higher 25(OH)D levels report better physical functioning, pain control, and overall well-being in the months following surgery [10,17,22].

One multicentre analysis noted that mental health domains in SF-36 were also positively influenced by vitamin D adequacy, suggesting a broader biopsychosocial role in recovery beyond physical metrics [30,31].

4.2 Vitamin D3 and Postoperative Complications

4.2.1 Infectious Complications

Vitamin D3 plays an immunomodulatory role, influencing both innate and adaptive immunity. Several studies have explored the association between low 25(OH)D levels and increased susceptibility to postoperative infections in patients undergoing hip fracture surgery. Deficient vitamin D status has been linked to a higher incidence of urinary tract infections (UTIs), surgical site infections (SSIs), and pneumonia during hospitalization [5,9,20].

One prospective observational study reported a significantly higher infection rate (23% vs. 10%) among patients with 25(OH)D levels below 20 ng/mL compared to those with sufficient levels [18]. Vitamin D's influence on cathelicidin expression, leukocyte function, and cytokine regulation is a plausible mechanistic link explaining this association [3,12].

4.2.2 Delayed or Failed Fracture Healing

While femoral neck fractures are typically treated surgically, healing at the osteotomy or fixation site still depends on biological and nutritional factors. Several observational studies suggest that low vitamin D levels may contribute to impaired fracture healing, including delayed union and non-union [11,14,21].

A retrospective analysis found that patients with 25(OH)D levels below 12 ng/mL had a significantly higher risk of radiographic non-union at 6 months postoperatively (OR 2.7; 95% CI, 1.4–5.3)[24]. Although causality cannot be definitively established, these findings support the hypothesis that vitamin D deficiency compromises bone remodelling during healing.

4.2.3 Risk of Falls and Secondary Fractures

Vitamin D deficiency is a well-established contributor to muscle weakness, impaired balance, and increased fall risk, all of which are particularly detrimental during the postoperative rehabilitation phase. Multiple studies reported higher rates of in-hospital falls, recurrent fractures, and post-discharge injuries among patients with low vitamin D status [6,13,19].

One RCT demonstrated a 41% reduction in secondary fracture incidence among patients receiving high-dose vitamin D3 supplementation postoperatively, compared to those without supplementation [29]. These findings underscore the importance of assessing and correcting vitamin D deficiency as part of comprehensive postoperative care.

4.3 Vitamin D3 and Mortality

4.3.1 Association Between 25(OH)D Deficiency and 30- and 90- Day Mortality

Several studies have examined short-term mortality following femoral neck fracture surgery in relation to baseline vitamin D3 status. Hypovitaminosis D (typically defined as 25(OH)D levels below 20 ng/mL) has been independently associated with increased risk of 30-day and 90-day postoperative mortality [3,6,17].

A large prospective cohort study demonstrated that patients in the lowest vitamin D tertile had significantly higher 90-day mortality rates (18.7% vs. 9.4%; $p = 0.02$) even after adjusting for age, sex, comorbidities, and surgical delay [11]. Another analysis reported a hazard ratio of 1.8 (95% CI: 1.2–2.6) for

30-day mortality in patients with severe deficiency (<10 ng/mL) [7]. These findings suggest that vitamin D status may serve as a simple, inexpensive prognostic marker in the early postoperative phase.

4.3.2 Long- Term Survival After Surgery

The relationship between vitamin D3 and long-term survival after femoral neck fracture has also gained research interest. Observational data consistently indicate that patients with deficient 25(OH)D levels have reduced 1-year and 2-year survival probabilities following hip fracture surgery [10,20,22].

While the underlying mechanisms are likely multifactorial (involving muscle weakness, immune dysregulation, and systemic inflammation) vitamin D's role in maintaining general physiological resilience may contribute to its prognostic value [9,27,28].

However, not all studies confirm a direct causal effect. Some analyses controlling for frailty and pre-fracture functional status attenuate or eliminate the association between vitamin D levels and long-term mortality, suggesting potential confounding [12,24]. This inconsistency highlights the need for well-designed RCTs focused on survival endpoints in this population.

4.4 Supplementation Strategies and Outcomes

4.4.1 Does Supplementation Improve Clinical Outcomes

Several interventional studies and meta-analyses have evaluated whether vitamin D3 supplementation improves postoperative outcomes in patients with hip fractures, including those affecting the femoral neck. Results suggest that supplementation may reduce complication rates, enhance functional recovery, and potentially lower mortality, although findings are not uniformly consistent across all endpoints [6,9,17].

A multicenter RCT reported significantly faster recovery of ambulation and reduced in-hospital complications in the group receiving 2000 IU of vitamin D3 daily compared to placebo [18]. Another study found improved functional outcomes (measured via HHS and Barthel Index) in supplemented patients, although mortality benefits did not reach statistical significance [3,29].

4.4.2 Efficacy of Different Doses and Regimens

Studies have explored a range of supplementation strategies from daily low-dose regimens (800–1000 IU) to intermittent high-dose boluses (e.g., 50,000 IU weekly or monthly). While most trials indicate benefit in correcting deficiency and supporting recovery, the optimal regimen remains debated [10,14,30].

High-dose bolus therapy has been associated with faster normalization of serum 25(OH)D levels, but also with concerns about transient hypercalcemia and paradoxical fall risk in frail elderly patients [5,21]. Continuous daily or weekly regimens appear safer and more physiologically consistent with the body's metabolic handling of vitamin D [20,32].

4.4.3 Risk of Hypervitaminosis and Drug Interactions

While vitamin D3 is generally well-tolerated, excessive dosing may lead to hypervitaminosis D, characterized by hypercalcemia, nausea, and, in rare cases, nephrocalcinosis. Most cases of toxicity are linked to cumulative dosing errors or unsupervised high-dose regimens [4,8].

Additionally, vitamin D3 supplementation may interact with drugs commonly used in the postoperative geriatric population, such as thiazide diuretics, anticonvulsants, and digoxin. Awareness of these interactions is critical for avoiding adverse effects, particularly in multimorbid patients undergoing fracture rehabilitation [15,16].

5. Discussion

5.1 Interpretation of Findings- Consistencies and Discrepancies

The available literature suggests a generally positive association between sufficient vitamin D3 status and favourable postoperative outcomes following femoral neck fracture surgery. Consistent patterns were observed across multiple studies linking adequate 25(OH)D levels to faster regaining of mobility, improved functional scores, fewer postoperative complications, and reduced mortality [2,7,9,17,20].

However, discrepancies exist some trials and cohort studies failed to demonstrate significant benefits, particularly regarding long-term survival or fracture healing outcomes [3,12,24]. These differences may reflect variations in study design, population characteristics, cut-off values for vitamin D deficiency, timing and dose of supplementation, and outcome definitions.

5.2 Potential Clinical Mechanisms of Vitamin D3 Action

The biological plausibility of vitamin D3's impact is well-supported. On the skeletal level, its role in calcium metabolism and osteoblast activation directly influences bone healing. In muscle, vitamin D3 modulates fibre composition, improves balance, and reduces fall risk [6,10,15].

On a systemic level, its immunomodulatory and anti-inflammatory effects may reduce susceptibility to infections and support global physiologic resilience, especially in frail postoperative patients [4,14,30].

5.3 Limitations of Included Studies

Many of the included studies were observational in nature, and therefore subject to residual confounding and bias. Sample sizes were often small, and definitions of "sufficiency" varied between studies (ranging from 20 to 30 ng/mL). Furthermore, outcome measures such as mobility or quality of life were inconsistently reported, and adherence to supplementation protocols was often not tracked [13,16,18].

Several randomized trials lacked long-term follow-up, limiting their ability to detect survival effects or fracture recurrence. Finally, most studies were conducted in single centres or region-specific populations, which may affect generalizability.

5.4 Limitations of This Review

As a narrative review, this work is inherently limited by the absence of formal meta-analytical synthesis. While thematic grouping allowed for meaningful clinical interpretation, the lack of statistical aggregation precludes estimation of pooled effect sizes.

The inclusion criteria, although rigorously applied, may still have missed relevant studies outside indexed databases. Additionally, the decision to focus on English-language publications may introduce language bias. Despite these limitations, the review offers a structured and up-to-date synthesis of clinically relevant evidence.

5.5 Practical Implications for Orthopaedic Surgeons and Rehabilitation Teams

Given the observed associations, orthopaedic teams should consider routine assessment of vitamin D3 status in patients undergoing femoral neck fracture surgery. Early identification and correction of deficiency may improve rehabilitation outcomes and reduce complications.

Interdisciplinary cooperation between orthopaedic surgeons, geriatricians, and rehabilitation specialists is essential. Supplementation strategies should be individualized, taking into account comorbidities, renal function, and potential interactions with other medications [8,19,27].

6. Conclusions

6.1 Summary of Key Findings

This review highlights the growing body of evidence supporting a clinically relevant association between vitamin D3 status and recovery outcomes following surgical treatment of femoral neck fractures. Adequate serum 25(OH)D levels are consistently linked with faster regaining of mobility, improved functional performance, lower risk of postoperative complications, and reduced early mortality [2,4,7,17,26,28].

Although some heterogeneity in study outcomes exists, particularly regarding long-term survival and bone union rates, the mechanistic plausibility and clinical trends justify proactive attention to vitamin D3 in this patient population [1,14,25].

6.2 Recommendations for Clinical Practice

Given the high prevalence of vitamin D3 deficiency in elderly patients sustaining hip fractures, routine preoperative screening of serum 25(OH)D should be considered part of standard care. In patients found to be deficient, timely supplementation (preferably using well-established regimens) may reduce risk of complications, support early mobilization, and facilitate functional recovery [8,10,19,23,33].

A multidisciplinary approach involving surgeons, internists, and rehabilitation professionals is critical for integrating vitamin D3 management into broader postoperative protocols. Special attention should be given to polypharmacy, renal function, and nutritional status when initiating supplementation [12,16,18,20].

6.3 Future Directions and Research Needs

While existing data are promising, several questions remain unresolved. High-quality, multicentre randomized controlled trials specifically targeting postoperative outcomes in vitamin D–deficient hip fracture patients are urgently needed. Future studies should compare various dosing regimens, explore combined interventions (e.g., vitamin D with calcium or protein), and assess long-term outcomes including re-fracture rates and institutionalization [3,6,9,22,24].

Moreover, future research should aim to standardize functional outcome reporting and include more diverse populations, particularly from low- and middle-income countries where both fracture burden and hypovitaminosis D are prevalent [29–32,34].

Disclosure

Author's contribution:

Conceptualization: PK,
Methodology: PK,
Software: PK, TS, PMi, MK
Check: PK, TS, JN, MK, KN
Formal analysis: PK, TS, JN, MK
Investigation: PK, MK, JN, BS
Resources: PK, MK, IC, BS
Writing- rough preparation: PK, MK, IC, BS
Writing- review and editing: PK, PM, KN
Visualization: PK, PMi, IC, KN
Supervision: PK, PM, PMi
Project administration: PK, PM

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