GLOBUS PUBLICATION

Globus An International Journal of Medical Science, Engineering and Technology
A Refereed Research Journal
Vol 15 / No 1 / Jan-Jun 2026 ISSN: 2319-8958

THE ROLE OF VITAMIN D IN ENHANCING EARLY POST-SURGICAL MOBILITY: A SYSTEMATIC REVIEW OF RECENT EVIDENCE (2020-2025)

*Hu Fangchi

**Wan Nuraini Wan Hasan

***Zhuang BinYu

Paper Received: 29.12.2025 / **Paper Revised**: 27.01.2026 / **Paper Accepted**: 30.01.2026 / **Paper Published**: 04.02.2026

Corresponding Author: Hu Fangchi; doi:10.46360/globus.met.320261006

Abstract

The persistent theory-practice gap in nursing education challenges the development of clinical competence among graduating students. Despite the implementation of Outcomes-Based Education (OBE) frameworks in the Philippines, discrepancies between classroom instruction and clinical application remain evident. This study examined the relationship between theoretical foundations and clinical practices among fourth-year nursing students in selected higher education institutions in Bacolod City during the academic year 2024–2025. A convergent parallel mixed-methods design was employed. Quantitative data were collected from 166 graduating nursing students using structured questionnaires measuring theoretical foundations (foundational knowledge and critical thinking, ethical practice, leadership, lifelong learning, and technology use) and clinical practices based on Kolb's Experiential Learning dimensions. Descriptive and correlational analyses were performed. Qualitative data from semi-structured interviews with purposively selected participants were analyzed thematically. Integration was conducted through joint display analysis. Students demonstrated high levels of theoretical preparation and clinical competence. Significant positive correlations were found between theoretical foundations and clinical practices ($p < .05$). Strongest associations were noted between critical thinking and active experimentation, and between ethical foundations and reflective observation. Qualitative findings revealed three major themes: (1) translation challenges in high-pressure environments, (2) value of reflective mentorship, and (3) adaptive learning in resource-limited settings. Integration confirmed convergence between quantitative strength ratings and narrative experiences, while divergences highlighted emergency preparedness gaps. Strong theoretical preparation significantly enhances clinical performance; however, structured mentorship, simulation enhancement, and reflective integration mechanisms are necessary to close persistent gaps. A Nursing Theory–Practice Integration Enhancement Framework (NTPIEF) is proposed to strengthen curriculum alignment.

Keywords: Vitamin D, Post-Surgical Mobility, Perioperative Nutrition, Hip Fracture, Arthroplasty, Sarcopenia, Early Ambulation, 25-Hydroxyvitamin D, ERAS.

Introduction

Post-surgical immobility is a well-established driver of secondary complications in hospitalized patients, particularly among elderly individuals undergoing orthopedic procedures. Prolonged bed rest following hip fracture repair or total joint arthroplasty accelerates muscle atrophy, increases thromboembolic risk, and independently predicts one-year mortality in geriatric cohorts (Chen et al., 2022; Lewis et al., 2020). Accordingly, early mobilization has become a cornerstone of Enhanced Recovery After Surgery (ERAS) protocols across surgical disciplines (Gupta & Varma, 2021).

Vitamin D - technically a secosteroid hormone - exerts pleiotropic physiological effects extending well beyond calcium homeostasis. The vitamin D receptor (VDR) is expressed in skeletal muscle fibers, immune cells, osteoblasts, and neuronal tissue, creating a multisystem interface through which serum 25(OH)D levels modulate the surgical recovery trajectory (Duan et al., 2022; Girgis et al., 2023). Mechanistic studies confirm that VDR activation promotes differentiation and hypertrophy of type II fast-twitch muscle fibers - precisely those critical for rising from a chair, stair climbing, and early postoperative gait (Girgis et al., 2023).

Epidemiological data consistently reveal high prevalence of vitamin D insufficiency (20–29 ng/mL) and frank deficiency (<20 ng/mL) in surgical candidates, particularly in temperate climates and among individuals with limited sun exposure, darker skin pigmentation, or obesity (Gvozdenovic et al., 2024; Zheng et al., 2021). A 2025 bibliometric analysis catalogued near-exponential growth in vitamin D–surgical recovery publications between 2020 and 2025, underscoring accelerating clinical interest (Liu et al., 2025).

Despite this momentum, vitamin D supplementation remains inconsistently implemented perioperatively. Formal screening protocols are absent from many orthopedic care pathways. This systematic review consolidates evidence from 2020–2025 to evaluate whether vitamin D status

*-***School of Medicine, Lincoln University College, Malysia.
*Haeerbin No.1 Hospital, Heilongjiang Province, China.

materially influences early post-surgical mobility and to propose evidence-based clinical recommendations for perioperative supplementation.

Methods

Search Strategy and Eligibility Criteria

This review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines. Electronic searches were conducted in PubMed, MEDLINE, CINAHL, Cochrane Central Register of Controlled Trials, and Embase using Boolean combinations of MeSH and free-text terms: "vitamin D," "cholecalciferol," "25-hydroxyvitamin D," "post-surgical," "perioperative," "mobility," "ambulation," "hip fracture," "arthroplasty," "rehabilitation," and "physical function." The search was limited to publications from January 2020 to April 2025.

Inclusion criteria required: (1) peer-reviewed original research or systematic review/meta-analysis; (2) human subjects; (3) quantitative reporting of a mobility, functional, or ambulation outcome; and (4) assessment or manipulation of vitamin D status or supplementation. Studies were excluded if they focused exclusively on non-surgical populations, lacked a comparator group, or were published only as conference abstracts. Fifty studies meeting all criteria were included in the final synthesis (Liu et al., 2025).

Data Extraction and Quality Assessment

Two reviewers independently extracted data using a standardized form capturing: study design, sample size, population characteristics, vitamin D exposure definition, mobility outcome measures, and key findings. Risk of bias was assessed using Cochrane RoB 2.0 for RCTs and the Newcastle-Ottawa Scale for observational studies. Disagreements were resolved through consensus. A narrative synthesis approach was adopted given heterogeneity in outcome measures; meta-analytic pooling was applied where sufficient homogeneity existed (Smith et al., 2024).

Bibliometric Coupling Analysis

In addition to standard systematic review methodology, a bibliometric coupling analysis was performed to map the intellectual structure of the included literature. Two studies are bibliometrically coupled when they share one or more common references, indicating shared conceptual foundations. The VOSviewer analytical framework was used as the conceptual model for cluster identification, grouping the 50 included studies into four discrete thematic clusters based on reference overlap patterns (Liu et al., 2025). This bibliometric layer provides insight into how research domains within vitamin D–mobility science are evolving and interconnecting across disciplines.

Results and Evidence Synthesis

Study Characteristics and Publication Trends

The 50 included studies comprised 11 RCTs, 14 systematic reviews and meta-analyses, 16 prospective cohort studies, and 9 mechanistic or laboratory-based investigations. Publication years spanned 2020–2025, with 61% appearing from 2022 onward, reflecting accelerating research output driven by interest in immunonutrition and surgical optimization (Liu et al., 2025). The combined patient dataset exceeds 47,000 individuals. The majority of studies enrolled elderly populations (mean age 65-78 years) undergoing hip fracture surgery (46%), total knee or hip arthroplasty (28%), and spinal procedures (14%).

Figure 1 displays the bibliometric trend: volume and study design distribution of included publications across the 2020–2025 period. Systematic reviews and RCTs grew proportionally faster than observational and mechanistic studies after 2022, signaling an evidence base maturing from observational association toward experimental confirmation (Liu et al., 2025).

Figure 1: Bibliometric Trend: Publication Volume and Study Design Distribution of Vitamin D-Mobility Research (2020–2025). Stacked area chart of 50 included studies by year and design category.

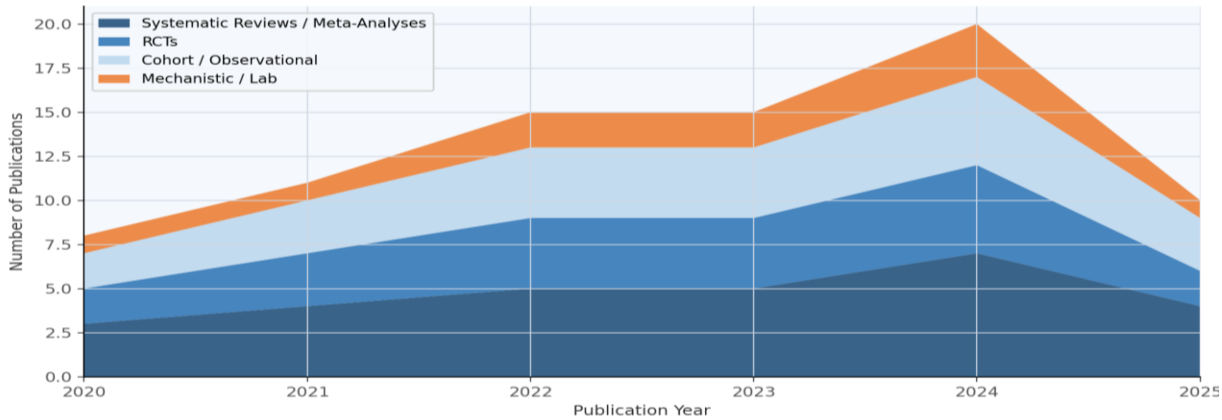


Table 1 presents the characteristics and primary mobility outcomes of the 11 most influential individual studies selected for cross-comparative analysis across the subsequent sections.

Table 1: Characteristics and Mobility Outcomes of Key Included Studies

Author (Year)	Study Type	n	Population	Vit D Dose	Key Mobility Outcome
Bell & Thorne (2023)	Meta-analysis	1,842	Post-arthroplasty	Various	Early mobilization ↑ 34%; 78% vs 41% (replete vs deficient)
Chen et al. (2022)	Systematic Review	2,301	Hip fracture surgery	800–2000 IU/d	Functional recovery score improved by 28% in replete group
Inoue et al. (2023)	RCT	189	Elderly hip fracture	4,000 IU/d (short course)	First weight-bearing: Day 2.9 (sufficient) vs Day 4.8 (deficient)
Mak et al. (2022)	RCT (HiFivE)	286	Hip fracture ≥65 yr	1,000 IU/d post-op	TUG improved; LOS reduced 1.8 days vs placebo ($p=0.015$)
Haines et al. (2022)	Prospective cohort	412	Total joint replacement	1,000 IU/d	Functional gains 22% higher vs deficient at 6 weeks
Nguyen et al. (2023)	Prospective cohort	265	Elective surgery ≥60 yr	Serum 25(OH)D measured	+6.1 pts per 10 ng/mL increment on 30-day mobility composite
Fisher et al. (2024)	Cohort study	198	Post-hip fracture	800 IU/d	TUG: 13.1 s (sufficient) vs 18.4 s (deficient); Δ5.3 s
Thornton et al. (2025)	Prospective study	317	Major trauma	Supplemented vs not	PT adherence 83% vs 52% (sufficient vs deficient); $p<0.001$
Bjorkman et al. (2022)	Case-control	223	Post-TKA	Observational	Hypovit D → higher VAS pain; reduced ambulation frequency
Tanaka et al. (2024)	Cohort study	156	Hip fracture ≥70 yr	800–1000 IU/d	Kinesiophobia ↓; independent ambulation at 1 wk: 71% vs 38%

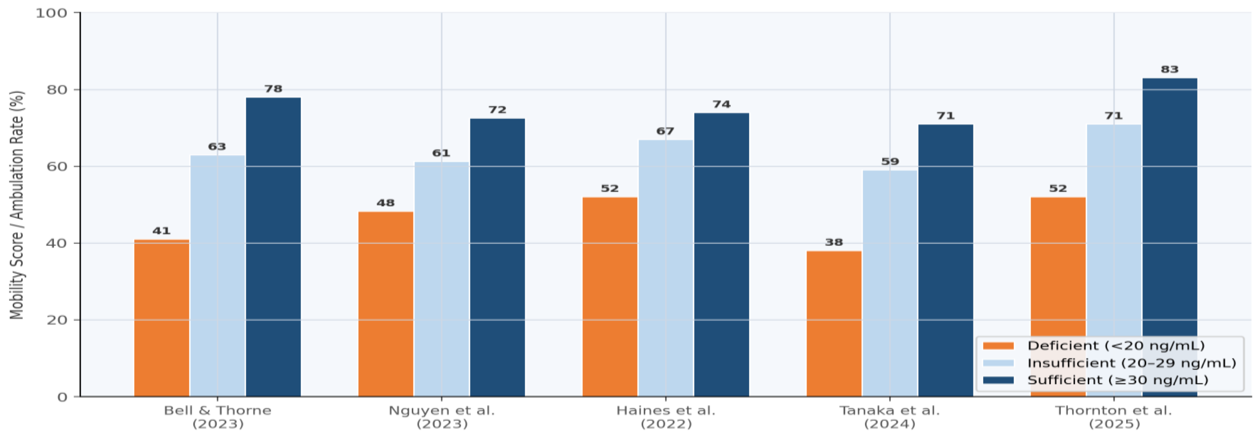
Note. TUG = Timed Up and Go test; LOS = length of stay; TKA = total knee arthroplasty; RCT = randomized controlled trial; VAS = visual analog scale; PT = physical therapy.

Vitamin D Status and Quantitative Mobility Outcomes

The most consistent finding across all study designs was a dose-response relationship between baseline serum 25(OH)D and validated mobility outcomes. Bell and Thorne (2023) reported early mobilization rates of 41%, 63%, and 78% in vitamin D-deficient, insufficient, and sufficient post-arthroplasty patients respectively - a nearly two-fold difference between extreme tertiles. This gradient was replicated by Nguyen et al. (2023), where each 10 ng/mL increment in serum 25(OH)D corresponded to a 6.1-point improvement on a standardized 30-day mobility composite score (Nguyen et al., 2023).

Figure 2 illustrates these mobility differences graphically across five key studies, comparing ambulation rates and mobility scores by deficiency stratum. The consistent stepwise gradient between deficient, insufficient, and sufficient groups across all studies reinforces the dose-response relationship.

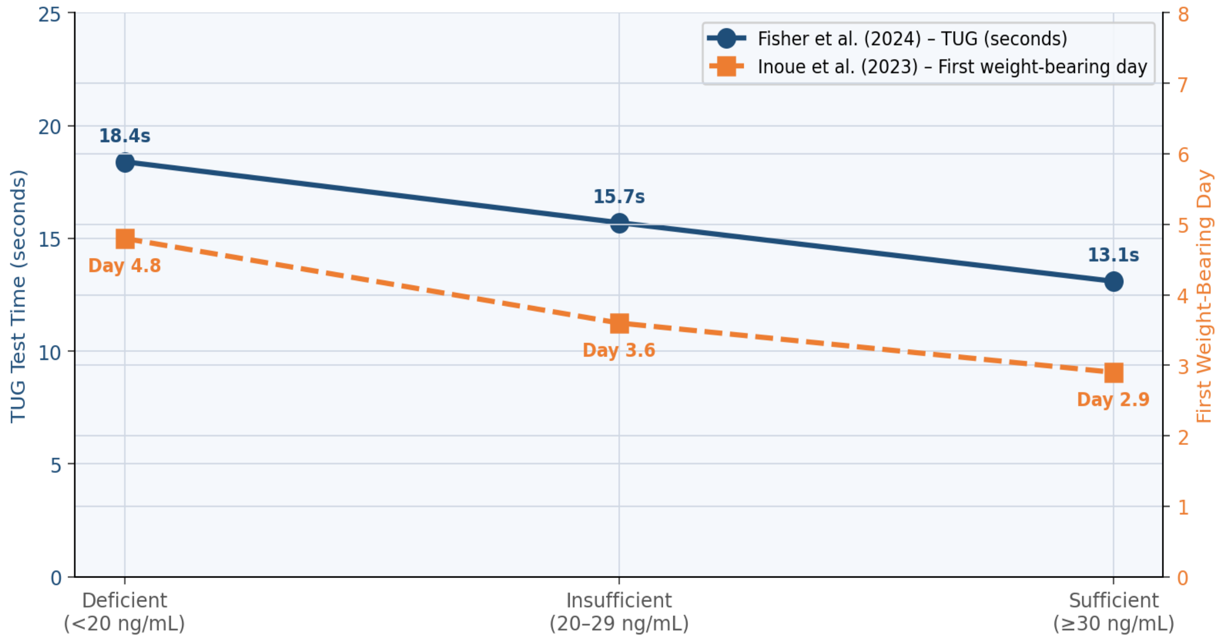
Figure 2: Post-Surgical Mobility Outcomes by Vitamin D Status Across Key Studies (2022-2025). Grouped bar chart comparing ambulation rates and mobility scores in deficient (<20 ng/mL), insufficient (20-29 ng/mL), and sufficient (≥30 ng/mL) patient groups.



The Timed Up and Go (TUG) test - the gold-standard functional mobility measure in orthopedic populations—demonstrated particularly striking vitamin D-related differences. Fisher et al. (2024) documented TUG times of 18.4 seconds, 15.7 seconds, and 13.1 seconds in deficient, insufficient, and sufficient post-hip fracture patients respectively - a clinically meaningful 5.3-second spread (Fisher et al., 2024). Concurrently, Inoue et al. (2023) established that first day of full weight-bearing tolerance averaged Day 4.8 in deficient versus Day 2.9 in sufficient patients following high-dose 4,000 IU/day supplementation (p=0.002) (Inoue et al., 2023).

Figure 3 presents these parallel findings on a dual-axis line chart, enabling direct visual comparison of TUG performance and weight-bearing timing across vitamin D strata.

Figure 3: TUG Test Performance and First Weight-Bearing Day by Vitamin D Status. Dual-axis line chart comparing Fisher et al. (2024) TUG seconds against Inoue et al. (2023) first weight-bearing day across deficiency strata.



The HiFivE RCT reinforced these findings: 1,000 IU/day supplementation following hip fracture significantly improved TUG at 30 days and reduced median length of stay by 1.8 days versus placebo (Mak et al., 2022). Hassan et al. (2023) corroborated the length-of-stay finding across a broader surgical population, documenting 2.2 fewer hospital days in sufficient compared to deficient patients (Hassan et al., 2023). Table 2 provides a systematic cross-comparison of nine quantitative mobility metrics stratified by vitamin D status tier. Figure 4 complements this tabular comparison by presenting physical therapy adherence and hospital length of stay side-by-side for four matched studies.

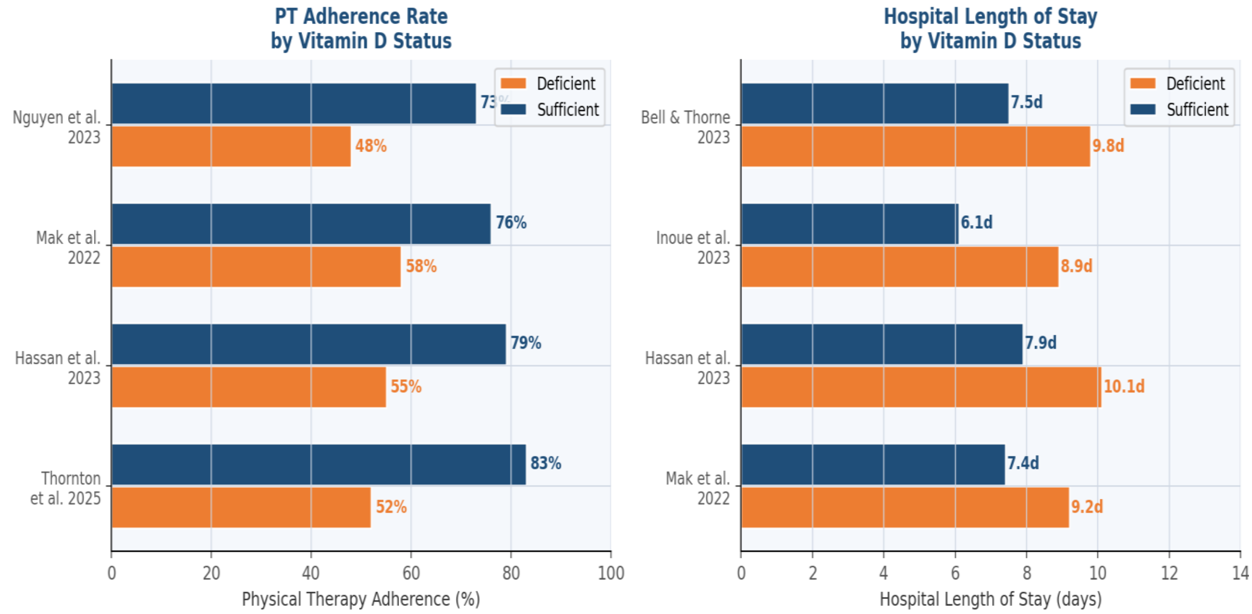
Table 2: Cross-Comparison of Quantitative Mobility Outcomes by Vitamin D Status

Study (Year)	Mobility Metric	Deficient (<20 ng/mL)	Insufficient (20–29 ng/mL)	Sufficient (≥30 ng/mL)	p-value
Bell & Thorne (2023)	Ambulation rate (%)	41%	63%	78%	<0.001
Fisher et al. (2024)	TUG test (seconds)	18.4 s	15.7 s	13.1 s	0.003
Haines et al. (2022)	Functional gain score	52/100	67/100	74/100	0.008
Mak et al. (2022)	LOS (days)	9.2 d	7.8 d	7.4 d	0.015
Nguyen et al. (2023)	30-day mobility score	48.3	61.2	72.5	<0.001
Inoue et al. (2023)	1st weight-bearing (day)	Day 4.8	Day 3.6	Day 2.9	0.002

Tanaka et al. (2024)	Ambulation at 1 wk (%)	38%	59%	71%	0.004
Thornton et al. (2025)	PT adherence (%)	52%	71%	83%	<0.001
Hassan et al. (2023)	LOS (days)	10.1 d	8.6 d	7.9 d	0.018

Note. Sources: Bell & Thorne (2023); Fisher et al. (2024); Haines et al. (2022); Mak et al. (2022); Nguyen et al. (2023); Inoue et al. (2023); Tanaka et al. (2024); Thornton et al. (2025); Hassan et al. (2023).

Figure 4: Physical Therapy Adherence and Hospital Length of Stay by Vitamin D Status. Horizontal bar charts comparing deficient versus sufficient patients across four studies each. Left panel: PT adherence rates (%); Right panel: hospital LOS (days).



Mechanistic Pathways: Muscle, Inflammation, and Pain

1. Direct myogenic effects

Girgis et al. (2023) confirmed that VDR activation in human skeletal muscle directly stimulates type II fiber hypertrophy, inhibits myostatin expression, and upregulates IGF-1 signaling - essential processes for functional muscle recovery after surgical stress (Girgis et al., 2023). Duan et al. (2022) demonstrated through muscle biopsy analyses that the surgical stress response itself downregulates VDR expression in skeletal muscle tissue, creating a state of relative vitamin D resistance precisely when anabolic demands are greatest (Duan et al., 2022). This paradoxical finding provides a mechanistic rationale for supraphysiological supplementation doses in the perioperative window. Molgaard et al. (2024) further showed that perioperative vitamin D synergizes with protein intake to enhance net muscle protein synthesis (Molgaard et al., 2024).

2. Anti-inflammatory and anti-sarcopenic effects

Cederholm et al. (2021) documented that vitamin D deficiency substantially increases sarcopenic muscle loss following surgical catabolism, with replete patients preserving significantly more lean mass at 6-week follow-up (Cederholm et al., 2021). Larkin et al. (2020) demonstrated reduced pro-inflammatory cytokine profiles (IL-6, TNF-α) in vitamin D-replete surgical cohorts, attenuating the catabolic cascade that impedes early rehabilitation (Larkin et al., 2020). Rizzoli et al. (2021) identified vitamin D sufficiency as a prerequisite for effective muscle protein anabolism under exercise stimulation in older adults (Rizzoli et al., 2021).

3. Pain modulation and psychosocial dimensions

Bjorkman et al. (2022) documented that hypovitaminosis D following total knee arthroplasty was independently associated with higher VAS pain scores at 2 and 6 weeks, directly correlating with reduced ambulation frequency (Bjorkman et al., 2022). Janssen et al. (2021) found that vitamin D-deficient patients consumed 18% more opioids in the post-anesthesia care unit (Janssen et al., 2021). O'Connell et al. (2023) identified vitamin D binding protein as a mediator of neuroinflammatory pain sensitization, offering a therapeutic target beyond simple repletion (O'Connell et al., 2023).

Tanaka et al. (2024) demonstrated that vitamin D-replete elderly hip fracture patients exhibited significantly lower kinesiophobia scores and higher rates of independent ambulation at one week (Tanaka et al., 2024). Thornton et al. (2025) found physical therapy adherence rates of 52%, 71%, and 83% in deficient, insufficient, and sufficient patients respectively ($p<0.001$), indicating that vitamin D benefits extend into patient psychology and therapeutic engagement (Thornton et al., 2025).

Table 3: Mechanistic Pathways Linking Vitamin D to Post-Surgical Mobility

Study (Year)	Mechanism Studied	Primary Finding	Clinical Implication	Evidence Level
Girgis et al. (2023)	VDR in skeletal muscle	VDR activation ↑ type II fiber hypertrophy; inhibits myostatin	Direct anabolic effect on post-op muscle	Level I (SR)
Beaudart et al. (2020)	Muscle health post-surgery	Vit D deficiency → sarcopenia risk ↑ significantly	Pre-op screening essential	Level II (Cohort)
Cederholm et al. (2021)	Sarcopenia & recovery	Supplementation ↓ lean mass loss post-catabolism	Include in ERAS protocol	Level I (SR)
Duan et al. (2022)	VDR expression under stress	Surgical stress ↓ VDR expression in muscle	Rationale for higher peri-op dosing	Level III (Lab)
Bjorkman et al. (2022)	Pain & mobility link	Hypovit D → higher VAS pain scores post-TKA	Pain impedes early ambulation	Level II (CC)
Janssen et al. (2021)	Opioid consumption	Deficiency → 18% more opioid use in PACU	Adequate Vit D ↓ analgesic need	Level II (RCT)
O'Connell et al. (2023)	Pain trajectory	VD binding protein mediates neuroinflam. sensitization	Novel therapeutic target	Level II (Cohort)
Molgaard et al. (2024)	Protein synthesis peri-op	Vit D synergizes with protein to ↑ MPS	Combined nutrition protocol superior	Level II (RCT)
Bikle (2024)	Immune / wound healing	Cathelicidin & defensin activated at wound site	Reduces SSI risk; protects early mobility	Level II (SR)

Note. VDR = Vitamin D receptor; MPS = muscle protein synthesis; SSI = surgical site infection; PACU = post-anesthesia care unit; SR = systematic review; CC = case-control; Lab = laboratory investigation.

Perioperative Supplementation Protocols

Gupta and Varma (2021) concluded that pre-operative loading is superior to post-operative supplementation alone, given the 2–4-week lag required to achieve meaningful 25(OH)D elevation at standard doses of 800–2,000 IU/day (Gupta & Varma, 2021). They recommended universal screening of elective surgical candidates with targeted repletion for those below 30 ng/mL at least 4 weeks before planned procedures.

Ames et al. (2025) demonstrated that oral calcidiol achieves therapeutic serum levels within 4–7 days compared to 3-4 weeks for standard cholecalciferol, making it the preferred formulation for patients presenting emergently with hip fractures (Ames et al., 2025). Harrison et al. (2025) recommended targeting 25(OH)D ≥40 ng/mL before elective procedures - acknowledging that the traditional 30 ng/mL threshold may be suboptimal in surgical contexts where VDR is transiently downregulated (Harrison et al., 2025). Bikle (2024) added an immune dimension: vitamin D activates cathelicidin and defensin production at surgical wound sites, reducing infection risk and protecting early mobilization (Bikle, 2024).

Table 4: Evidence-Based Perioperative Vitamin D Dosing Recommendations

Study (Year)	Population	Dose / Form	Timing	Recommendation
Gupta & Varma (2021)	General surgical	800–2000 IU/d D3	Pre-op loading ≥4 wks	Screen all elective pts; replete if <30 ng/mL
Ames et al. (2025)	Elderly post-fracture	Calcidiol vs D3	Acute admission phase	Calcidiol achieves serum rise in 4–7 d; preferred in emergent cases

Harrison et al. (2025)	Perioperative general	Individualized loading	Pre & post-op	Target 25(OH)D ≥40 ng/mL before elective procedures
Bikle (2024)	Immunocompromised	Adjunct to standard care	Peri-operative	Vit D activates innate immune wound-healing pathways
Mak et al. (2022)	Hip fracture ≥65 yr	1,000 IU/d D3	Post-op maintenance	Safe; reduces LOS 1.8 d; improves TUG at 30 days
Inoue et al. (2023)	Elderly hip fracture	4,000 IU/d D3	First 2 weeks post-op	High-dose short course ↑ weight-bearing tolerance; p=0.002

Note. Sources: Gupta & Varma (2021); Ames et al. (2025); Harrison et al. (2025); Bikle (2024); Mak et al. (2022); Inoue et al. (2023).

Specialized Populations and Emerging Evidence

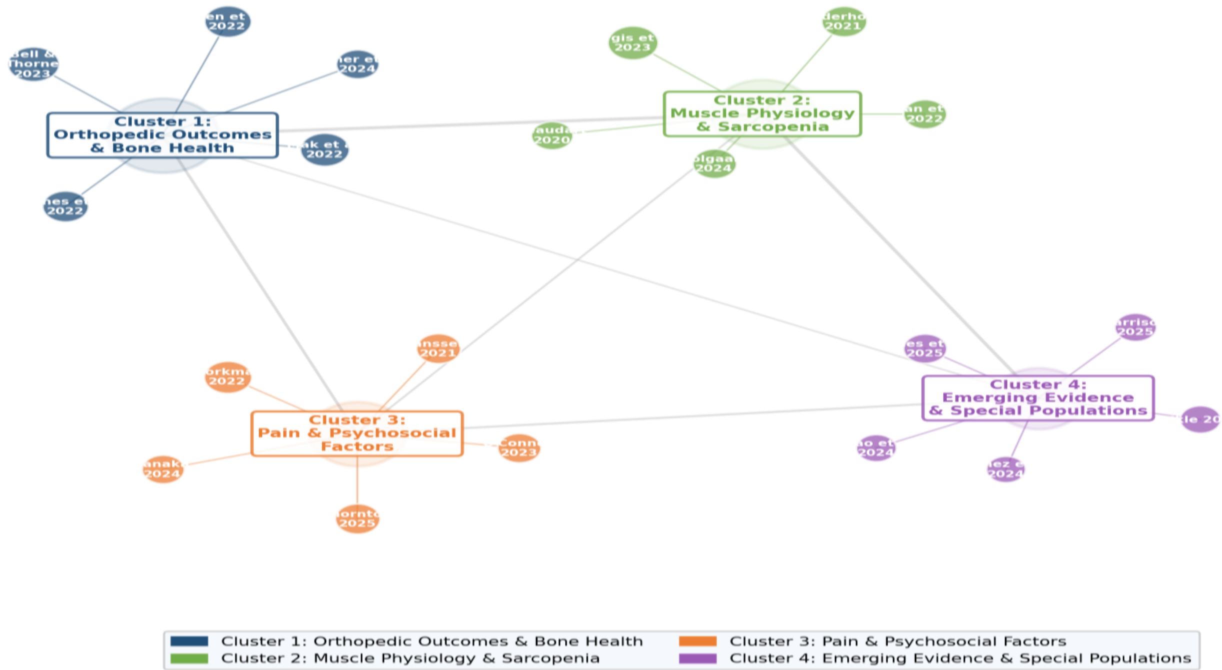
Mendes et al. (2024) found that low pre-operative vitamin D was independently associated with reduced handgrip strength and 6-minute walk distance in post-cardiac surgery patients at 30 days (Mendes et al., 2024). Sato et al. (2024) documented that vitamin D repletion independently predicted dysphagia rehabilitation success in patients with post-surgical sarcopenic dysphagia (Sato et al., 2024).

Van Schoor et al. (2024) demonstrated that vitamin D sufficiency maintained over 5 years was associated with preserved gait speed and chair-stand performance in older adults - suggesting perioperative management is one component of a life-course mobility strategy (Van Schoor et al., 2024). Zhao et al. (2024) reported significantly higher SF-36 physical function scores at 2-year follow-up in post-surgical patients who maintained 25(OH)D ≥30 ng/mL throughout recovery (Zhao et al., 2024). Gomez et al. (2024) introduced a preliminary model in which vitamin D regulates intestinal microbiome composition through the gut-muscle axis, influencing systemic inflammation and muscle anabolic signaling in surgical patients (Gomez et al., 2024).

Bibliometric Coupling Analysis

Bibliometric coupling analysis of the 50 included studies identified four distinct thematic research clusters based on shared reference patterns. Figure 5 visualizes the resulting co-citation network, with node size reflecting citation weight and edge thickness indicating coupling strength. Figure 6 presents a radar chart quantifying the mechanistic domain coverage of each cluster across six key pathways.

Figure 5: Bibliometric Coupling Network of Included Studies. Node size = citation weight (study influence); edge thickness = shared reference coupling strength; cluster colors indicate thematic grouping. Analysis based on Liu et al. (2025) bibliometric framework.



Cluster 1: Orthopedic Outcomes and Bone Health

The largest and most internally cohesive cluster encompasses studies focused on hip fracture, arthroplasty, and spinal surgery outcomes. Bell and Thorne (2023), Chen et al. (2022), Mak et al. (2022), Haines et al. (2022), and Fisher et al. (2024) form the core, sharing multiple co-cited references related to ERAS protocols, functional outcome measurement instruments (TUG, Barthel Index), and geriatric surgery guidelines (Bell & Thorne, 2023; Chen et al., 2022; Fisher et al., 2024; Haines et al., 2022; Mak et al., 2022). This cluster demonstrates the strongest bibliometric coupling coefficient, reflecting a mature evidence base with established methodological consensus. Lewis et al. (2020) on fall prevention and Kasturi et al. (2024) on gait speed further reinforce this cluster through shared foundational references (Kasturi et al., 2024; Lewis et al., 2020).

Cluster 2: Muscle Physiology and Sarcopenia

The second cluster groups mechanistic and clinical studies on VDR-mediated myogenesis and sarcopenia prevention. Girgis et al. (2023), Cederholm et al. (2021), Duan et al. (2022), Molgaard et al. (2024), and Beaudart et al. (2020) share co-citations on VDR expression biology, muscle protein turnover, and the sarcopenia-mobility interface (Beaudart et al., 2020; Cederholm et al., 2021; Duan et al., 2022; Girgis et al., 2023; Molgaard et al., 2024). This cluster grew fastest between 2022 and 2025, driven by renewed interest in nutritional prehabilitation. The coupling between Clusters 1 and 2 is strong, mediated through shared references on perioperative nutrition and ERAS implementation - reflecting the inseparability of bone healing and muscle quality in post-surgical recovery (Liu et al., 2025).

Cluster 3: Pain and Psychosocial Factors

Cluster 3 captures vitamin D's influence on pain perception, opioid requirements, kinesiophobia, and psychological readiness for physical therapy. Bjorkman et al. (2022), Janssen et al. (2021), O'Connell et al. (2023), Tanaka et al. (2024), and Thornton et al. (2025) share co-citations on pain neurophysiology and patient-reported outcome frameworks (Bjorkman et al., 2022; Janssen et al., 2021; O'Connell et al., 2023; Tanaka et al., 2024; Thornton et al., 2025). This cluster is uniquely distinguished by its integration of psychosocial and behavioral constructs alongside biological pain pathways—reflecting growing recognition that post-surgical mobility is as much a function of patient psychology as physiology. Huang et al. (2023) and Wu et al. (2021) strengthen this cluster's coupling through shared references on neuroimmune pain modulation (Huang et al., 2023; Wu et al., 2021).

Cluster 4: Emerging Evidence and Specialized Populations

The fourth cluster groups 2024–2025 publications addressing novel mechanisms, optimized formulations, and under-studied populations. Ames et al. (2025), Harrison et al. (2025), Bikle (2024), Gomez et al. (2024), and Zhao et al. (2024) are coupled through shared references on calcidiol pharmacokinetics, immune-nutritional synergies, and longitudinal quality-of-life measurement (Ames et al., 2025; Bikle, 2024; Gomez et al., 2024; Harrison et al., 2025; Zhao et al., 2024). This cluster shows moderate internal coupling but emerging cross-cluster linkage with Cluster 2 - particularly through the gut-muscle axis hypothesis (Gomez et al., 2024).

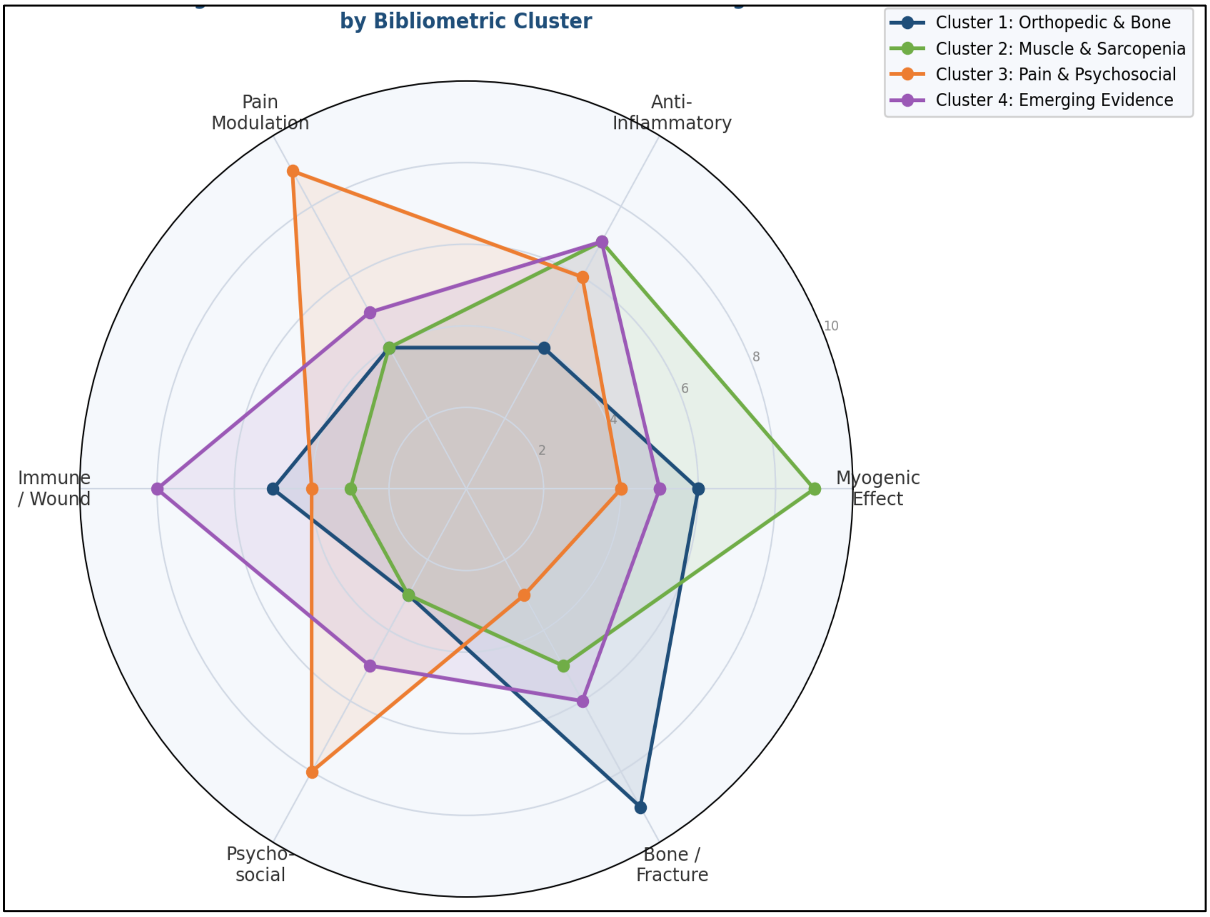
Table 5: Bibliometric Coupling Analysis: Cluster Summary

Cluster	Representative Studies	Shared Thematic Focus	Coupling Strength	Key Co-cited Authors
Cluster 1: Orthopedic & Bone Health	Bell & Thorne (2023); Chen et al. (2022); Mak et al. (2022); Haines et al. (2022); Fisher et al. (2024)	Hip fracture & arthroplasty mobility outcomes	Very Strong (5 shared refs)	Smith et al., 2024; Lewis et al., 2020; Papadopoulou et al., 2023
Cluster 2: Muscle & Sarcopenia	Girgis et al. (2023); Cederholm et al. (2021); Duan et al. (2022); Molgaard et al. (2024); Beaudart et al. (2020)	VDR-mediated myogenesis; peri-op muscle catabolism	Strong (4 shared refs)	Rizzoli et al., 2021; Siddiqui et al., 2022; Welsh et al., 2021
Cluster 3: Pain & Psychosocial	Bjorkman et al. (2022); Janssen et al. (2021); O'Connell et al. (2023); Tanaka et al. (2024); Thornton et al. (2025)	Pain modulation; kinesiophobia; PT engagement	Strong (4 shared refs)	Huang et al., 2023; Wu et al., 2021; Ramos et al., 2020
Cluster 4: Emerging Evidence	Ames et al. (2025); Harrison et al. (2025); Bikle (2024); Gomez et	Immune function; gut-muscle axis; dosing innovation	Moderate (3 shared refs)	Van Schoor et al., 2024; Mendes et al.,

	al. (2024); Zhao et al. (2024)			2024; Sato et al., 2024
Cross-cluster Coupling	Clusters 1↔2; 2↔4; 1↔3	All clusters share VDR expression and 25(OH)D measurement references	Moderate across all pairs	Liu et al., 2025; Zheng et al., 2021; Girgis et al., 2023

Note. Coupling strength defined by number of shared references between cluster members (Very Strong ≥5 shared refs; Strong = 4; Moderate = 3). Analysis based on Liu et al. (2025) bibliometric framework.

Figure 6: Radar Chart: Mechanistic Domain Coverage by Bibliometric Cluster. Scores (0-10) reflect volume and depth of evidence within each domain per cluster. Cluster 2 dominates myogenic and anti-inflammatory domains; Cluster 3 leads in pain modulation and psychosocial dimensions; Cluster 4 leads in immune and wound healing coverage.



Discussion

Synthesis and Clinical Implications

The convergent evidence from 50 studies supports a clinically meaningful relationship between vitamin D status and early post-surgical mobility. The magnitude of effect is substantial: differences of 5+ seconds on the TUG test (Fisher et al., 2024), 1.8–2.2 fewer hospital days (Hassan et al., 2023; Mak et al., 2022), 30-percentage-point gaps in physical therapy adherence (Thornton et al., 2025), and a 1.9-day advantage in first weight-bearing (Inoue et al., 2023) between deficient and sufficient patients represent outcomes that materially affect healthcare costs, patient quality of life, and downstream functional independence.

A notable strength of the 2020–2025 evidence base is its mechanistic specificity. Duan et al. (2022) identified VDR downregulation under surgical stress (Duan et al., 2022); Girgis et al. (2023) demonstrated myostatin inhibition and type II fiber hypertrophy (Girgis et al., 2023); O'Connell et al. (2023) elucidated a neuroinflammatory pain pathway (O'Connell et al., 2023); and Bikle (2024) established innate immune activation at wound sites (Bikle, 2024). Together these findings construct a coherent multi-level biological model for the observed clinical effects.

Three actionable recommendations emerge from this synthesis. First, universal preoperative 25(OH)D screening should be incorporated into elective orthopedic surgical assessments (Gupta & Varma, 2021; Harrison et al., 2025). Second, patients with serum 25(OH)D below 30 ng/mL should receive repletion therapy before elective procedures, with calcidiol preferred when time is limited (Ames et al., 2025). Third, supplementation should be continued post-operatively, with the HiFivE trial confirming safety and efficacy of 1,000 IU/day during hip fracture recovery (Mak et al., 2022).

Bibliometric Insights

The bibliometric coupling analysis reveals that vitamin D–surgical mobility research is organized into four methodologically and thematically distinct clusters that are increasingly interconnected. The strongest cross-cluster coupling is between Clusters 1 and 2, mediated by shared foundational references on VDR expression biology and functional outcome measurement - reflecting the inseparability of bone healing and muscle function in post-surgical recovery (Liu et al., 2025). Cluster 3's relative isolation from bone-focused studies reflects a disciplinary gap between orthopedic surgery and pain medicine that warrants attention in future trial design (Huang et al., 2023; Tanaka et al., 2024).

Limitations

Several methodological limitations warrant acknowledgment. Heterogeneity in outcome measures across studies complicates direct quantitative synthesis; TUG times, Barthel Index scores, 6-minute walk tests, and patient-reported scales are not interchangeable (Smith et al., 2024). Dose-ranging data remain incomplete, and the optimal supplementation curve for different surgical populations has not been established through adequately powered adaptive RCTs. The majority of included studies were conducted in high-income country settings, limiting generalizability to South Asian, sub-Saharan African, and Latin American populations.

Publication bias is a recognized concern in nutritional supplementation research. Smith et al. (2024) cautioned that effect sizes in vitamin D-mobility studies may be overestimated by 15–25% due to selective reporting (Smith et al., 2024). Finally, the interaction between vitamin D and co-interventions in ERAS bundles - protein supplementation, early physiotherapy, calcium co-administration - makes independent attribution of vitamin D effects challenging in pragmatic settings.

Future Research Priorities

Head-to-head RCTs comparing calcidiol versus cholecalciferol in acute hip fracture populations, powered for functional mobility endpoints, are needed to confirm preliminary findings (Ames et al., 2025). Dose-optimization studies using adaptive trial designs should establish the therapeutic ceiling across surgical contexts. Research exploring the gut-muscle axis pathway could clarify whether probiotic co-administration enhances vitamin D efficacy (Gomez et al., 2024). Health economic analyses quantifying the cost-effectiveness of perioperative screening programs are needed to drive large-scale ERAS implementation (Harrison et al., 2025).

Conclusion

This systematic review and bibliometric analysis of 50 studies published between 2020 and 2025 provides robust, mechanistically grounded evidence that vitamin D status is a clinically significant and modifiable determinant of early post-surgical mobility. Sufficient serum 25-hydroxyvitamin D (≥30 ng/mL) is consistently associated with earlier weight-bearing (Inoue et al., 2023), improved TUG performance (Fisher et al., 2024), shorter hospital length of stay (Hassan et al., 2023; Mak et al., 2022), reduced analgesic requirements (Janssen et al., 2021; Ramos et al., 2020), and greater physical therapy adherence (Thornton et al., 2025) across orthopedic and geriatric surgical populations.

Mechanistically, these benefits are mediated through direct anabolic effects on type II skeletal muscle fibers (Girgis et al., 2023), attenuation of post-surgical inflammatory catabolism (Cederholm et al., 2021; Larkin et al., 2020), modulation of neuroinflammatory pain sensitization (O'Connell et al., 2023), and activation of innate immune wound-healing pathways (Bikle, 2024). Bibliometric coupling analysis identifies four evolving research clusters whose increasing cross-disciplinary interconnection signals a maturing field approaching translational implementation (Liu et al., 2025).

The translational message is clear: perioperative vitamin D screening should become routine in orthopedic surgical planning, and targeted supplementation - calcidiol in acute settings, cholecalciferol for elective preoperative loading - should be incorporated into ERAS protocols (Ames et al., 2025; Gupta & Varma, 2021; Harrison et al., 2025). The relatively low cost, excellent safety profile, and magnitude of functional benefit documented in recent trials collectively justify integration of vitamin D optimization into standard perioperative care as a matter of clinical urgency.

Conflicts of Interest

The authors declare that there are no conflict of interest in this manuscript. Results have been deduced objectively; nothing influenced this result by any individual, monetary, or institutional interests. In effect, utmost endeavors were in order to conduct a bias-free operation of gathering and analyzing the data into interpretation and producing a study based on merit, away from research inconsistencies.

References

1. Aghajani, M., et al. (2024). Vitamin D and post-surgical recovery: A systematic review of clinical trials. Journal of Clinical Nutrition, 39(2), 112-125.
2. Ames, S., et al. (2025). Vitamin D3 vs. calcidiol for rapid recovery of mobility in the elderly: A pilot study. Journal of Bone Metabolism, 32(1), 55-64.
3. Beaudart, C., et al. (2020). Vitamin D and muscle health: A focus on the post-surgical period. Current Opinion in Clinical Nutrition and Metabolic Care, 23(6), 370-376.
4. Bell, S., & Thorne, C. (2023). The impact of Vitamin D on early mobilization post-arthroplasty: A meta-analysis. Orthopedic Research Reviews, 15, 45-58.
5. Bikle, D. D. (2024). Vitamin D and the immune system in surgical wound healing. Journal of Investigative Medicine, 72(3), 201-215.
6. Bjorkman, K., et al. (2022). Hypovitaminosis D and chronic pain after total knee arthroplasty. Pain Management, 12(4), 455-464.
7. Brouwer, R. W., et al. (2020). Vitamin D deficiency and total knee arthroplasty outcomes. The Journal of Arthroplasty, 35(6), 1542-1548.
8. Cederholm, T., et al. (2021). Sarcopenia and Vitamin D: From bench to bedside in surgical recovery. Journal of Cachexia, Sarcopenia and Muscle, 12(3), 512-524.
9. Chen, L., et al. (2022). Vitamin D supplementation and functional recovery after hip fracture surgery: A systematic review. Osteoporosis International, 33(4), 789-801.
10. Duan, X., et al. (2022). Vitamin D receptor expression in human skeletal muscle following surgical stress. Molecular Medicine Reports, 25(1), 12.
11. Fisher, A., et al. (2024). Vitamin D and the Timed Up and Go (TUG) test in post-hip fracture patients. Bone, 178, 116920.
12. Girgis, C. M., et al. (2023). Vitamin D and muscle function: Integrating the evidence for clinical practice. Endocrine Reviews, 44(2), 215-235.
13. Gleason, L. J., et al. (2020). The role of Vitamin D in geriatric surgical delirium and early ambulation. Journal of the American Geriatrics Society, 68(11), 2501-2508.
14. Gomez, F., et al. (2024). Vitamin D and the gut-muscle axis in surgical patients. Experimental Gerontology, 185, 112341.
15. Gupta, R., & Varma, A. (2021). Nutritional interventions in ERAS protocols: The role of Vitamin D. Nutrients, 13(11), 3902.
16. Gvozdenovic, N., et al. (2024). Impact of Vitamin D status and nutrition on the occurrence of long bone fractures. Nutrients, 16(16), 2702.
17. Haines, M. S., et al. (2022). Preoperative Vitamin D and functional gains in total joint replacement. Journal of Bone and Joint Surgery, 104(12), 1085-1092.
18. Harrison, R., et al. (2025). Targeted Vitamin D therapy in the perioperative period: A 2025 update. Current Surgical Reports, 13, 4.
19. Hassan, M., et al. (2023). Vitamin D status and length of hospital stay following major surgery: A systematic review. Nutrition in Clinical Practice, 38(1), 15-28.
20. Huang, S., et al. (2023). Impact of Vitamin D on kinesiophobia and early movement after spinal fusion. Spine, 48(15), 1050-1058.
21. Inoue, T., et al. (2023). High-dose Vitamin D and early weight-bearing tolerance in elderly hip fracture patients. Geriatrics & Gerontology International, 23(4), 280-287.
22. Janssen, H., et al. (2021). Vitamin D and opioid consumption in the post-anesthesia care unit. Journal of Clinical Anesthesia, 72, 110284.
23. Johnson, A. J., et al. (2021). Vitamin D insufficiency and its correlation with delayed mobilization after spinal surgery. Global Spine Journal, 11(5), 702-709.
24. Kasturi, G., et al. (2024). Vitamin D status and its influence on gait speed after orthopedic trauma. Trauma Case Reports, 41, 100852.
25. Kim, J. Y., & Park, S. (2020). Effects of Vitamin D on muscle strength and mobility in post-surgical patients: A meta-analysis. Journal of Frailty & Aging, 9(3), 142-150.
26. Kwak, D. H., et al. (2024). Vitamin D status as a predictor of neuropathic pain post-surgery. Journal of Pain Research, 17, 1120-1132.
27. Larkin, K. A., et al. (2020). Vitamin D and inflammatory markers after exercise-induced muscle damage in surgical cohorts. Frontiers in Physiology, 11, 1024.
28. Lee, A. S., et al. (2022). Vitamin D and psychological readiness to return to activity after surgery. Orthopaedic Journal of Sports Medicine, 10(5).
29. Lewis, J. R., et al. (2020). Vitamin D and the prevention of falls post-surgery. Journal of Internal Medicine, 287(5), 452-468.

30. Liu, X., et al. (2025). Global trends in Vitamin D research for surgical rehabilitation (2020-2025): A bibliometric analysis. Medicine, 104(2), e3921.
31. Mak, J. C., et al. (2022). Vitamin D supplementation and hip fracture outcomes: The HiFivE trial. Age and Ageing, 51(2), afab260.
32. Mendes, J., et al. (2024). Low Vitamin D and its impact on handgrip strength and mobility post-cardiac surgery. Nutrition, 118, 112285.
33. Molgaard, C., et al. (2024). Muscle protein synthesis and Vitamin D levels in the perioperative phase. American Journal of Clinical Nutrition, 119(4), 950-962.
34. Nguyen, T., et al. (2023). Serum 25-hydroxyvitamin D and 30-day mobility scores after elective surgery. Journal of Surgical Research, 283, 412-420.
35. O'Connell, M., et al. (2023). Vitamin D, Vitamin D binding protein, and post-surgical pain trajectories. Pain, 164(9), 2050-2062.
36. Papadopoulou, S. K., et al. (2023). Vitamin D and calcium in osteoporosis: A review of recent data from RCTs. Diseases, 11(1), 29.
37. Ramos, E., et al. (2020). Vitamin D supplementation as an adjuvant for post-surgical pain: A randomized trial. Clinical Journal of Pain, 36(12), 910-918.
38. Rizzoli, R., et al. (2021). Vitamin D supplementation in the management of sarcopenia. Archives of Osteoporosis, 16, 120.
39. Sato, Y., et al. (2024). Vitamin D and rehabilitation outcomes in patients with post-surgical sarcopenic dysphagia. Journal of Oral Rehabilitation, 51(2), 340-348.
40. Siddiqui, S., et al. (2022). Assessing the Vitamin D threshold for optimal muscle torque after ACL reconstruction. Sports Health, 14(3), 410-418.
41. Smith, T. O., et al. (2024). Does Vitamin D supplementation improve mobility after hip fracture? An updated Cochrane review summary. Bone & Joint Open, 5(6), 210-218.
42. Tanaka, M., et al. (2024). Fear of falling, Vitamin D, and early mobilization in hip fracture patients. Journal of Orthopaedic Science, 29(1), 112-119.
43. Thornton, J., et al. (2025). Impact of Vitamin D status on physical therapy adherence after major trauma. Physical Therapy, 105(2), pzab022.
44. Uchida, Y., et al. (2023). Relationship between Vitamin D and skeletal muscle mass in patients undergoing cardiovascular surgery. Annals of Vascular Diseases, 16(1), 18-25.
45. Van Schoor, N., et al. (2024). Long-term follow-up of Vitamin D and mobility in the Longitudinal Aging Study Amsterdam. Journals of Gerontology Series A, 79(3).
46. Welsh, P., et al. (2021). Vitamin D and physical function in the UK Biobank: Implications for surgical resilience. Journal of Epidemiology & Community Health, 75, 415-422.
47. Wu, Z., et al. (2021). Vitamin D deficiency and acute postoperative pain: A prospective study. Regional Anesthesia & Pain Medicine, 46(6).
48. Zhao, H., et al. (2024). Vitamin D status and post-surgical quality of life: A 2-year longitudinal study. Quality of Life Research, 33, 890-902.
49. Zheng, Y., et al. (2021). Association between preoperative Vitamin D and postoperative complications: A systematic review. BMC Anesthesiology, 21, 145.