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Original Research

Association Between Vitamin D Status and Functional Recovery in Patients with Lower-Limb Fractures: A Prospective Observational Study

Dr. Jarpula Rajesh¹, Dr. Sujan Nethi², Dr. Nulavai Vamsi Krishna³

¹Associate Professor, Department of Orthopaedics, Government Medical College, Bhadradi Kothagudem Telangana, India

²Assistant Professor, Department of Orthopaedics, Government Medical College, Bhadradi Kothagudem Telangana, India

³Senior Resident, Department of Orthopaedics, Government Medical College, Bhadradi Kothagudem Telangana, India

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Abstract

Background: Vitamin D contributes to calcium homeostasis, callus mineralisation, and skeletal muscle function, but its relationship with early recovery after lower-limb fractures remains incompletely defined. **Objectives:** To determine the association between baseline serum vitamin D status and functional recovery, weight-bearing, and radiological union in adults with lower-limb fractures. **Methods:** This prospective observational study included 80 adults treated for lower-limb fractures at Government Medical College/Government General Hospital, Bhadradi Kothagudem, Telangana, India, from October 2024 to May 2025. Serum 25-hydroxyvitamin D was classified as deficient, insufficient, or sufficient. Lower Extremity Functional Scale scores were recorded at baseline, six weeks, and 12 weeks. Time to full weight-bearing and radiological union were documented. Correlation and multivariable regression analyses evaluated independent associations. **Results:** The mean age was 44.6 ± 15.2 years, and 52 (65.0%) participants were male. Vitamin D deficiency was present in 34 (42.5%), insufficiency in 25 (31.3%), and sufficiency in 21 (26.3%) patients. At 12 weeks, mean functional scores were 53.6 ± 10.2 , 61.4 ± 8.8 , and 68.2 ± 7.6 in the deficient, insufficient, and sufficient groups, respectively. Sufficient patients achieved full weight-bearing and radiological union earlier. Serum vitamin D correlated positively with the 12-week functional score and inversely with time to union. After adjustment, each 1 ng/mL increase in vitamin D was associated with a 0.49-point higher functional score. **Conclusion:** Lower baseline vitamin D status was associated with poorer short-term functional recovery and slower fracture-healing indicators. Baseline assessment can support risk stratification, although interventional studies are required before routine supplementation strategies are inferred.

Keywords: Vitamin D; lower-limb fractures; functional recovery; Lower Extremity Functional Scale; fracture union; prospective observational study.

Keywords: *Pseudomonas aeruginosa*; Antimicrobial resistance; Biofilm; Crystal violet.

Introduction

Lower-limb fractures represent a substantial cause of pain, disability, loss of mobility, and interruption of occupational and social activity. Recovery depends on stable fracture fixation, preservation of vascularity, rehabilitation, and the patient's biological capacity for bone repair. Despite technically adequate treatment, the pace of union and functional improvement varies considerably between individuals. Age, fracture severity, open injury, smoking, obesity, diabetes, and other systemic factors influence healing; however, potentially correctable nutritional and metabolic factors receive less consistent attention in routine trauma care.

Vitamin D is central to calcium and phosphate homeostasis, skeletal mineralisation, and neuromuscular performance. Serum 25-hydroxyvitamin D is the accepted marker of vitamin D status. Concentrations below 20 ng/mL are commonly classified as deficient, values of 20-29.9 ng/mL as insufficient, and levels of at least 30 ng/mL as sufficient [1]. During fracture repair, adequate mineral availability is required for hard-callus formation and remodelling. Vitamin D also affects osteoblast and osteoclast activity, muscle strength, balance, and mobilisation, providing several pathways through which low status could influence both radiological healing and functional recovery [2]. Nevertheless, the clinical relationship is complex, and earlier systematic evidence has remained inconsistent [3].

Hypovitaminosis D is frequently reported in orthopaedic trauma populations. A systematic review of acute fracture patients estimated a pooled prevalence close to 70%, indicating that low vitamin D status is not limited to elderly or osteoporotic individuals [4]. Studies among patients with foot and ankle injuries have similarly demonstrated a high frequency of insufficient concentrations [5]. Observational evidence has suggested that persistent deficiency is associated with delayed clinical healing in adults with extremity fractures [6]. In patients undergoing ankle fracture fixation, deficient perioperative concentrations were also correlated with poorer patient-reported symptoms, activities of daily living, and quality-of-life outcomes [7]. Conversely, supplementation trials have produced mixed findings, partly because of heterogeneous fracture patterns, dosing regimens, baseline vitamin D levels, and outcome definitions.

Functional recovery is a clinically meaningful endpoint because radiological union alone does not fully represent restoration of walking, stair negotiation, work capacity, and daily independence. The Lower Extremity Functional Scale is a practical, responsive instrument for measuring disability across diverse lower-limb musculoskeletal conditions [8]. However, prospective data linking baseline vitamin D categories with serial functional scores and fracture-healing indicators remain limited in Indian tertiary-care settings.

Address for Correspondence Dr. Jarpula Rajesh, Associate Professor, Department of Orthopaedics, Government Medical College, Bhadradi Kothagudem Telangana, India.

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The present study was undertaken to evaluate vitamin D status among adults with lower-limb fractures and to examine its relationship with subsequent recovery. The objectives were to compare Lower Extremity Functional Scale scores at baseline, six weeks, and 12 weeks across vitamin D categories; assess differences in time to full weight-bearing and radiological union; determine correlations between serum vitamin D and recovery measures; and identify whether vitamin D concentration independently predicted 12-week functional outcome after adjustment for relevant clinical factors.

Materials and Methods

Study design and setting: This single-centre prospective observational study was conducted in the Department of Orthopaedics, Government Medical College/Government General Hospital, Bhadradi Kothagudem, Telangana, India. Recruitment, evaluation, and follow-up were undertaken from October 2024 to May 2025.

Study participants: Adults aged 18 years or older with an acute radiologically confirmed fracture involving the femur, tibia, ankle, patella, or another lower-limb site were assessed consecutively. Patients managed operatively or conservatively were eligible when baseline blood sampling and functional assessment could be completed. Pathological fractures, periprosthetic fractures, established metabolic bone disease other than vitamin D deficiency, advanced chronic kidney or liver disease, malabsorption, long-term corticosteroid therapy, polytrauma preventing functional assessment, and refusal to participate were exclusion criteria.

Sample size and sampling: The sample size was estimated to detect a correlation of at least 0.35 between serum vitamin D and the 12-week functional score, with a two-sided alpha of 0.05 and 80% power. After allowance for potential attrition, the target was rounded to 80 participants. Consecutive sampling was used to reduce selection bias.

Baseline assessment and vitamin D classification: Demographic characteristics, body mass index, comorbidities, fracture site, open or closed status, and management modality were recorded using a structured case-record form. A venous sample was obtained at enrolment, before newly prescribed vitamin D therapy, and serum 25-hydroxyvitamin D was measured using a chemiluminescent immunoassay. Concentrations were classified as deficient (<20 ng/mL), insufficient (20–29.9 ng/mL), or sufficient (≥30 ng/mL), according to commonly used clinical thresholds [1]. Treatment, rehabilitation, supplementation, and progression of weight-bearing remained under the treating orthopaedic team; the study assigned no intervention.

Outcome assessment: Lower-limb function was measured using the 20-item Lower Extremity Functional Scale, scored from 0 to 80, with higher scores indicating better function [8]. Assessments were completed after initial stabilisation and repeated at six and 12 weeks. A 12-week score of at least 60 was predefined as satisfactory recovery. Full weight-bearing was recorded when permitted without assistive restriction. Radiological union was defined by progressive bridging callus across at least three cortices, clinical stability, and minimal fracture-site pain. Delayed union was recorded when adequate progression was absent by 24 weeks.

Statistical analysis: Data were analysed using IBM SPSS Statistics version 26.0. Continuous variables were expressed as mean ± standard deviation and categorical variables as frequency and percentage. Normality was assessed using the Shapiro-Wilk test. Vitamin D groups were compared using one-way analysis of variance and the chi-square test. Pearson correlation assessed associations between vitamin D and recovery outcomes. Multiple linear regression evaluated predictors of the 12-week functional score, and binary logistic regression assessed unsatisfactory recovery. A two-sided p-value <0.05 was statistically significant.

Ethical considerations: Necessary Permissions were obtained before starting the study. Written informed consent was obtained from all participants, and confidentiality was maintained.

Results

A total of 80 patients with lower-limb fractures were enrolled, and complete baseline, biochemical, radiological, and functional follow-up data were available for all participants. The mean age was 44.6 ± 15.2 years, with an age range of 18–76 years. Fifty-two (65.0%) patients were male and 28 (35.0%) were female. The mean body mass index was 25.1 ± 3.8 kg/m².

Tibial fractures were the most frequent, occurring in 31 (38.8%) patients, followed by femoral fractures in 24 (30.0%), ankle fractures in 17 (21.3%), and patellar or other lower-limb fractures in 8 (10.0%). Closed fractures accounted for 66 (82.5%) cases, while 14 (17.5%) were open. Operative management was undertaken in 63 (78.8%) patients, and 17 (21.3%) received conservative treatment. At least one associated comorbidity was present in 25 (31.3%) participants (Table 1).

Table 1. Baseline demographic and clinical characteristics of the participants (N = 80)

Characteristic	Category	Frequency/Mean	Percentage
Age, years	Mean ± SD	44.6 ± 15.2	–
Sex	Male	52	65.0
	Female	28	35.0
Body mass index, kg/m ²	Mean ± SD	25.1 ± 3.8	–
Fracture site	Femur	24	30.0
	Tibia	31	38.8
	Ankle	17	21.3
	Patella/other sites	8	10.0
Fracture type	Closed	66	82.5
	Open	14	17.5
Management	Operative	63	78.8
	Conservative	17	21.3
Associated comorbidity	Present	25	31.3
	Absent	55	68.8

The mean serum 25-hydroxyvitamin D concentration was 21.8 ± 9.6 ng/mL. Vitamin D deficiency was identified in 34 (42.5%) patients, insufficiency in 25 (31.3%), and sufficiency in 21 (26.3%). Overall, 59 (73.8%) participants had a concentration below 30 ng/mL. The three

vitamin D groups showed no statistically significant baseline differences in age, sex, body mass index, fracture site, fracture type, treatment modality, comorbidity, or initial Lower Extremity Functional Scale score (all $p > 0.05$).

Mean baseline functional scores were 14.7 ± 6.0 in the deficient group, 15.2 ± 5.7 in the insufficient group, and 15.6 ± 6.1 in the sufficient group ($p = 0.871$). Scores improved in all groups, but recovery was greater with higher vitamin D status. At six weeks, mean scores were 31.2 ± 8.4 , 37.8 ± 7.9 , and 43.5 ± 8.1 , respectively ($p < 0.001$). At 12 weeks, the corresponding values were 53.6 ± 10.2 , 61.4 ± 8.8 , and 68.2 ± 7.6 ($p < 0.001$). The mean improvement from baseline to 12 weeks increased progressively from 38.9 ± 9.7 in the deficient group to 52.6 ± 7.8 in the sufficient group (Table 2).

Table 2. Functional and fracture-healing outcomes according to vitamin D status

Outcome	Deficient (n=34)	Insufficient (n=25)	Sufficient (n=21)	p-value
Baseline LEFS score	14.7 ± 6.0	15.2 ± 5.7	15.6 ± 6.1	0.871
LEFS score at 6 weeks	31.2 ± 8.4	37.8 ± 7.9	43.5 ± 8.1	<0.001
LEFS score at 12 weeks	53.6 ± 10.2	61.4 ± 8.8	68.2 ± 7.6	<0.001
Improvement in LEFS score at 12 weeks	38.9 ± 9.7	46.2 ± 8.6	52.6 ± 7.8	<0.001
Time to full weight-bearing, weeks	13.8 ± 3.1	11.9 ± 2.7	10.4 ± 2.4	<0.001
Time to radiological union, weeks	18.2 ± 3.7	16.4 ± 3.1	14.9 ± 2.8	0.002
Satisfactory recovery at 12 weeks, n (%)	12 (35.3)	16 (64.0)	19 (90.5)	<0.001
Delayed union, n (%)	8 (23.5)	3 (12.0)	1 (4.8)	0.146

LEFS: Lower Extremity Functional Scale. Continuous variables are presented as mean $\pm$ standard deviation.

Satisfactory functional recovery, defined as a 12-week score of at least 60, was achieved by 47 (58.8%) patients. The proportions were 35.3% in the deficient group, 64.0% in the insufficient group, and 90.5% in the sufficient group ($p < 0.001$). Patients with sufficient vitamin D attained full weight-bearing earlier than the insufficient and deficient groups: 10.4 ± 2.4 , 11.9 ± 2.7 , and 13.8 ± 3.1 weeks, respectively ($p < 0.001$).

Time to radiological union also differed significantly across the groups. Mean union time was 18.2 ± 3.7 weeks in vitamin D-deficient patients, 16.4 ± 3.1 weeks in insufficient patients, and 14.9 ± 2.8 weeks in sufficient patients ($p = 0.002$). Delayed union occurred in 12 (15.0%) patients, comprising 8 (23.5%) in the deficient group, 3 (12.0%) in the insufficient group, and 1 (4.8%) in the sufficient group. This difference did not reach statistical significance ($p = 0.146$).

Serum vitamin D concentration demonstrated a moderate positive correlation with the 12-week functional score ($r = 0.48$, $p < 0.001$) and with improvement from baseline ($r = 0.44$, $p < 0.001$). Inverse correlations were observed with time to full weight-bearing ($r = -0.41$, $p < 0.001$) and time to radiological union ($r = -0.36$, $p = 0.001$).

In multivariable linear regression, serum vitamin D remained independently associated with the 12-week functional score. Each 1 ng/mL increase was associated with a 0.49-point higher adjusted score (95% confidence interval: 0.26-0.72; $p < 0.001$). Increasing age and open fracture were independently associated with lower scores (Table 3). In adjusted logistic regression, a vitamin D concentration below 30 ng/mL was associated with higher odds of unsatisfactory recovery compared with sufficient status (adjusted odds ratio: 5.84; 95% confidence interval: 1.18-28.90; $p = 0.031$).

Table 3. Multivariable linear regression analysis of factors associated with the 12-week LEFS score

Variable	Regression coefficient (β)	95% confidence interval	p-value
Serum vitamin D, per 1 ng/mL increase	0.49	0.26 to 0.72	<0.001
Age, per one-year increase	-0.18	-0.34 to -0.02	0.029
Male sex	1.42	-2.76 to 5.60	0.500
Body mass index	-0.21	-0.72 to 0.30	0.415
Open fracture	-7.18	-12.39 to -1.97	0.008
Operative management	2.31	-2.84 to 7.46	0.374
Presence of comorbidity	-3.86	-7.92 to 0.20	0.062

Discussion

The present prospective study identified a high burden of hypovitaminosis D and a consistent relationship between baseline vitamin D status and early recovery after lower-limb fracture. Nearly three-quarters of participants had deficiency or insufficiency. Although baseline functional scores were comparable, separation between the groups became evident at six weeks and increased by 12 weeks. Higher vitamin D concentrations were associated with better functional scores, earlier unrestricted weight-bearing, and shorter radiological union time. The association with the 12-week functional score persisted after adjustment for age, sex, body mass index, fracture type, treatment modality, and comorbidity.

The prevalence of low vitamin D status in this cohort is comparable with the pooled estimate of approximately 70% reported among acute fracture patients [4]. Smith et al. also documented frequent hypovitaminosis D in patients with foot and ankle injuries [5]. Such findings indicate that deficiency is relevant across age groups and fracture mechanisms, including populations living in regions with abundant sunlight. The present results further extend prevalence observations by demonstrating a graded functional pattern across deficient, insufficient, and sufficient categories. Warner et al. reported that vitamin D deficiency correlated with inferior patient-reported symptoms, daily activity, and quality-of-life scores after ankle fracture fixation [7], which supports the direction of the current functional findings.

Several biological pathways could explain the observed association. Vitamin D contributes to calcium and phosphate availability, callus mineralisation, bone remodelling, muscle performance, and post-injury mobilisation [2]. Earlier clinical work suggested that persistent deficiency after fracture was associated with a greater occurrence of delayed clinical union [6]. In the current study, serum vitamin D showed

a moderate positive correlation with functional gain and an inverse correlation with time to weight-bearing and radiological union. These findings are compatible with biological plausibility, but the observational design does not establish that low vitamin D directly caused delayed recovery.

Evidence from supplementation studies remains less uniform. A prospective randomised trial by Haines et al. found no difference in nonunion after a single high-dose supplement among patients with hypovitaminosis D [9]. Similarly, the Vita-Shock trial detected no statistically significant benefit in prespecified comparisons, although exploratory analyses suggested a possible improvement with higher-dose regimens [10]. A later systematic review concluded that vitamin D supplementation alone produced limited and inconsistent effects on union and functional outcomes [11]. Therefore, the current findings should be interpreted as an association with baseline biological status rather than proof that routine supplementation improves every fracture outcome.

Increasing age and open fracture were independently associated with lower 12-week functional scores. This accords with large-scale evidence showing that injury severity, open fracture, obesity, comorbidity, and vitamin D deficiency contribute to nonunion risk [12]. Metabolic abnormalities are also frequent among established nonunion cases [13]. A 2024 systematic review found vitamin D deficiency to be a significant nonunion indicator in several, but not all, included studies [14]. Collectively, these data support selective metabolic assessment in patients with poor progress, while highlighting the need for adequately powered trials using standardised functional and radiological endpoints.

LIMITATIONS

This study was conducted at a single tertiary-care institution with a modest sample, limiting external generalisability. Fracture sites and treatment approaches were heterogeneous, and rehabilitation intensity, dietary intake, sunlight exposure, smoking, and post-enrolment supplementation were not standardised. Functional follow-up focused on the first 12 weeks, while delayed union required longer observation. Residual confounding remains possible despite multivariable adjustment, and causal inference cannot be drawn from an observational design.

Conclusion

Baseline vitamin D status was associated with early functional and fracture-healing outcomes in adults with lower-limb fractures. Patients with sufficient concentrations achieved higher 12-week Lower Extremity Functional Scale scores, earlier full weight-bearing, and faster radiological union than patients with deficient or insufficient levels. Serum vitamin D remained an independent predictor of functional recovery after adjustment for demographic and clinical factors. These findings support vitamin D assessment within the metabolic evaluation of fracture patients, particularly when recovery is slow or risk factors for impaired healing are present. The results establish association rather than treatment efficacy. Multicentre prospective studies and randomised trials are required to determine whether targeted correction improves important outcomes.

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