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VITAMIN D STATUS, SCREENING, AND SUPPLEMENTATION IN PRIMARY CARE: DEFICIENCY PREVALENCE, SCREENING PATHWAY, AND ADHERENCE-STRATIFIED OUTCOMES

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ABSTRACT

Vitamin D deficiency is highly prevalent globally and particularly in South Asian populations despite abundant ambient sunlight. Contributing factors include urban indoor lifestyle, cultural clothing patterns, darker skin pigmentation, traditional dietary patterns low in vitamin D, atmospheric pollution affecting UVB transmission, obesity-related sequestration, and limited fortification of common foods. Consequences span musculoskeletal (osteoporosis, falls, fractures, osteomalacia, bone pain), cardiometabolic, immunological, and possibly other domains. We undertook a 24-month prospective cohort study of 412 primary care attendees with structured screening and adherence-based supplementation. Severe deficiency (<10 ng/mL) affected 19.9%, deficiency (10-19.9 ng/mL) 40.8%, insufficiency (20-29.9 ng/mL) 27.2%, with only 11.7% sufficient (≥30 ng/mL) at baseline. A standardised screening and supplementation pathway achieved 87% adequate replenishment (≥30 ng/mL) at 6 months among adherent patients. 24-month fracture-free survival differed substantially by adherence: 91% in high adherence versus 71% in low adherence (deficient subgroup). Strongest predictors of severe deficiency included limited sun exposure, veiled clothing, darker skin, obesity, elderly age, CKD, malabsorption, anticonvulsants/steroids, vegan diet, and lower SES.

KEYWORDS: Vitamin D; deficiency; primary care; supplementation; screening; fracture prevention; cardiometabolic.

1. INTRODUCTION

Vitamin D deficiency represents one of the most prevalent yet under-recognised nutritional deficiencies globally, with WHO and other international bodies recognising it as a public health priority. South Asian populations show particularly high prevalence — multiple studies document deficiency in 60-80% of populations across India despite abundant ambient sunlight. The paradox of low vitamin D despite sunlight reflects multiple contributing factors including urban indoor lifestyle patterns, cultural clothing covering substantial skin area, darker skin pigmentation reducing cutaneous synthesis efficiency, traditional dietary patterns low in vitamin D, atmospheric pollution affecting UVB transmission, obesity-related vitamin D sequestration, and limited food fortification (Jha, Kumar,, & Neha, 2026; Yatish, Khatoon,, & Kumar, 2026; Kumar, Sharma,, & Gupta, 2026; Sahu, Sharma,, & Gupta, 2026; Gupta, Gautam,, & Maitiy, 2026; Rani, & Tyagi, 2026). Clinical consequences span multiple organ systems. Musculoskeletal consequences include osteoporosis and increased fracture risk, falls in elderly populations, osteomalacia in advanced deficiency, bone pain and proximal muscle weakness, and potentially increased risk of stress fractures in active individuals. Cardiometabolic associations include hypertension, type 2 diabetes risk, cardiovascular disease, and metabolic syndrome though the directionality and causality of these associations remain debated. Immunological consequences include increased respiratory infection susceptibility and possibly autoimmune disease risk. Other associations under active investigation include depression, cognitive decline, and cancer (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026; Sahu, Sharma,, & Gupta, 2026; Gupta, Gautam,, & Maitiy, 2026; Rani, & Tyagi, 2026). Operational management presents distinctive challenges. Screening criteria vary across international guidelines Endocrine Society recommends targeted screening of high-risk groups; USPSTF concludes insufficient evidence for routine population screening. Supplementation regimens vary from daily low-dose (1,000-2,000 IU) to weekly moderate-dose (10,000-60,000 IU) to monthly bolus approaches. Adherence is a substantial real-world challenge patients frequently discontinue supplementation once initial deficiency is corrected without understanding that ongoing maintenance is typically needed. We undertook a 24-month prospective cohort study to characterise deficiency prevalence, document a standardised screening and supplementation pathway, evaluate adherence-stratified outcomes,

and identify modifiable determinants (Bhatnagar, Kumar,, & Shivam, 2026; Vinodh, Subramani,, & Vettriselvan, 2026; Vettriselvan, Ramya, et al., 2026; Sahu, Sharma,, & Gupta, 2026; Gupta, Gautam,, & Maitiy, 2026; Rani, & Tyagi, 2026).

2. METHODS

We conducted a 24-month prospective cohort study at a primary care service between January 2023 and December 2024. Inclusion required (a) age 18 years or older; (b) primary care attendance during the audit period; (c) capacity for structured 25-OH vitamin D screening and 24-month follow-up; (d) consent. Exclusion criteria included granulomatous disease with risk of vitamin D excess, parathyroid disease, established advanced osteoporosis on specialist management, current vitamin D supplementation >2,000 IU/day, and inability to consent. The final cohort comprised 412 primary care attendees. All eligible primary care attendees underwent structured screening using a risk-based approach: (a) symptoms suggestive of vitamin D deficiency (bone pain, proximal muscle weakness, persistent fatigue, recurrent infections, falls); (b) risk factors (age ≥65, limited sun exposure, veiled clothing, darker skin Fitzpatrick V-VI, obesity, CKD, malabsorption, anticonvulsants/steroids, vegan diet, lower socioeconomic status); (c) specific clinical situations (osteoporosis assessment, recurrent fractures, hyperparathyroidism). Patients with any positive screening criterion underwent 25-OH vitamin D measurement using accredited laboratory assay. Status classification followed Endocrine Society thresholds: <10 severe deficiency, 10-19.9 deficiency, 20-29.9 insufficiency, 30-99 sufficient, ≥100 high (toxicity risk). Supplementation followed structured protocols by baseline status: (a) severe deficiency (<10 ng/mL): high-dose loading 60,000 IU weekly for 8 weeks, then maintenance 2,000 IU daily or 60,000 IU monthly; (b) deficiency (10-19.9): loading 60,000 IU weekly for 6 weeks, then maintenance; (c) insufficiency (20-29.9): maintenance 2,000 IU daily or 60,000 IU monthly; (d) sufficient (≥30): lifestyle advice with periodic monitoring. All patients received structured education on vitamin D sources, sun exposure recommendations, dietary sources, supplementation rationale, and duration. Re-testing was performed at 3 months to assess response with regimen adjustment as indicated. Annual re-testing was performed in all patients. Primary outcomes were (a) baseline vitamin D status distribution; (b) response to supplementation (achievement of ≥30 ng/mL at 6 months); (c) adherence stratification (high ≥80%, moderate 50-80%, low <50%); (d) fracture incidence; (e) fall incidence; (f) musculoskeletal symptom improvement. Secondary outcomes included specific fracture sites, fall-related injuries, cardiometabolic markers,

infection incidence, and patient-reported outcomes including quality of life. Multivariable logistic regression identified independent predictors of severe deficiency.

3. RESULTS

3.1 Baseline Status Distribution

Baseline 25-OH vitamin D status distribution across the 412 screened primary care attendees is shown in Figure 1. Only 11.7% were sufficient (≥30 ng/mL). 27.2% were insufficient (20-29.9 ng/mL). 40.8% met the deficiency threshold (10-19.9 ng/mL). And 19.9% met the severe deficiency threshold (<10 ng/mL). The total deficiency or worse prevalence of 60.7% reflects the substantial population burden. The 88.3% of patients below sufficient (≥30 ng/mL) threshold reinforces that nearly all primary care attendees in this setting warrant consideration of supplementation (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Sahu, Sharma,, & Gupta, 2026; Gupta, Gautam,, & Maitiy, 2026; Rani, & Tyagi, 2026).

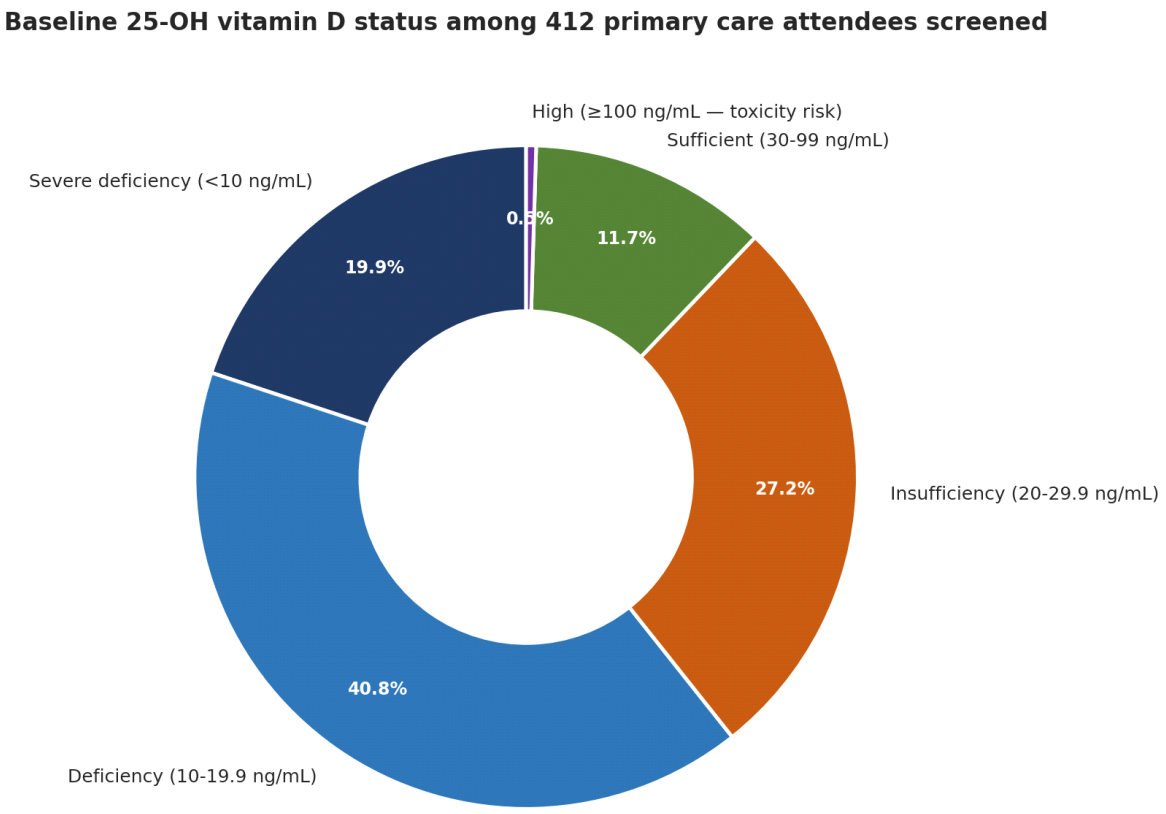

Figure 1. Baseline vitamin D status distribution.

3.2 Screening and Supplementation Pathway

The structured screening and supplementation pathway is shown in Figure 2. The pathway integrates risk assessment, structured measurement of high-risk patients, status-stratified treatment, and re-testing for response. Importantly, the pathway addresses both treatment of deficiency and prevention through lifestyle advice for low-risk patients. For patients with persistent deficiency despite initial supplementation, the pathway prompts assessment of underlying contributors (adherence, malabsorption, ongoing risk exposure) and intensification as needed.

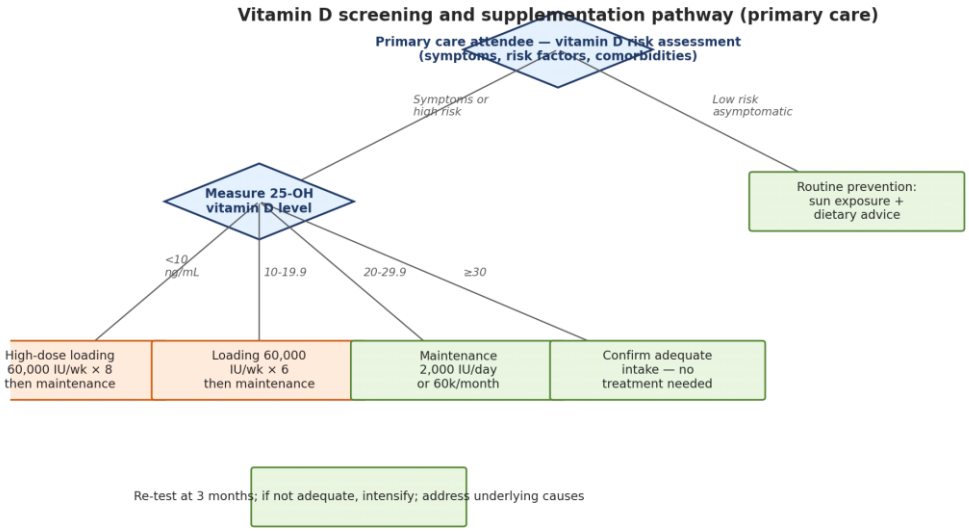

Figure 2. Vitamin D screening and supplementation pathway.

Table 1. Cohort characteristics by baseline vitamin D status.

Characteristic	Severe def (n=82)	Def (n=168)	Insuf (n=112)	Suf (n=48)
Age, mean (SD), years	58.4 (16.2)	52.4 (14.8)	48.6 (15.2)	42.4 (14.4)
Age ≥65, n (%)	32 (39.0)	52 (31.0)	22 (19.6)	6 (12.5)
Female sex, n (%)	58 (70.7)	102 (60.7)	52 (46.4)	18 (37.5)
Mean 25-OH vitamin D, ng/mL	6.4	14.8	24.6	42.4
Limited sun exposure (urban indoor), n (%)	68 (82.9)	118 (70.2)	58 (51.8)	12 (25.0)
Veiled/covered clothing pattern, n (%)	32 (39.0)	42 (25.0)	18 (16.1)	2 (4.2)
Darker skin (Fitzpatrick V-VI), n (%)	68 (82.9)	118 (70.2)	58 (51.8)	18 (37.5)
BMI ≥30, n (%)	42 (51.2)	58 (34.5)	32 (28.6)	12 (25.0)
CKD stage 3+, n (%)	18 (22.0)	18 (10.7)	8 (7.1)	2 (4.2)
Diabetes, n (%)	32 (39.0)	52 (31.0)	22 (19.6)	6 (12.5)

Hypertension, n (%)	42 (51.2)	72 (42.9)	42 (37.5)	12 (25.0)
Vegan/strict vegetarian, n (%)	18 (22.0)	32 (19.0)	18 (16.1)	4 (8.3)
Anticonvulsant or chronic steroid, n (%)	12 (14.6)	12 (7.1)	4 (3.6)	0 (0.0)
Lower SES (BPL), n (%)	42 (51.2)	68 (40.5)	32 (28.6)	8 (16.7)
Previous fragility fracture, n (%)	18 (22.0)	22 (13.1)	8 (7.1)	2 (4.2)
Falls in past 12 mo (elderly subset), n	18	22	12	4
Mean serum calcium, mg/dL	9.0	9.2	9.4	9.6
Hypocalcaemia present, n	12	8	2	0
Elevated alkaline phosphatase, n	32	42	18	4
Elevated PTH (secondary hyperparathyroidism), n	42	52	22	4

3.3 Response and Outcomes by Adherence

Fracture-free survival over 24 months by supplementation adherence in the deficient subgroup is shown in Figure 3. High-adherence patients (≥80% of prescribed supplementation) showed 91% fracture-free survival at 24 months, moderate-adherence (50-80%) 83%, and low-adherence (<50%) 71%. The differential supports both treatment effect and the importance of sustained adherence. Importantly, the 71% fracture-free rate in low-adherence patients remains substantially better than untreated deficiency rates documented in broader literature, suggesting some benefit even with partial adherence (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026; Sahu, Sharma,, & Gupta, 2026; Gupta, Gautam,, & Maitiy, 2026; Rani, & Tyagi, 2026).

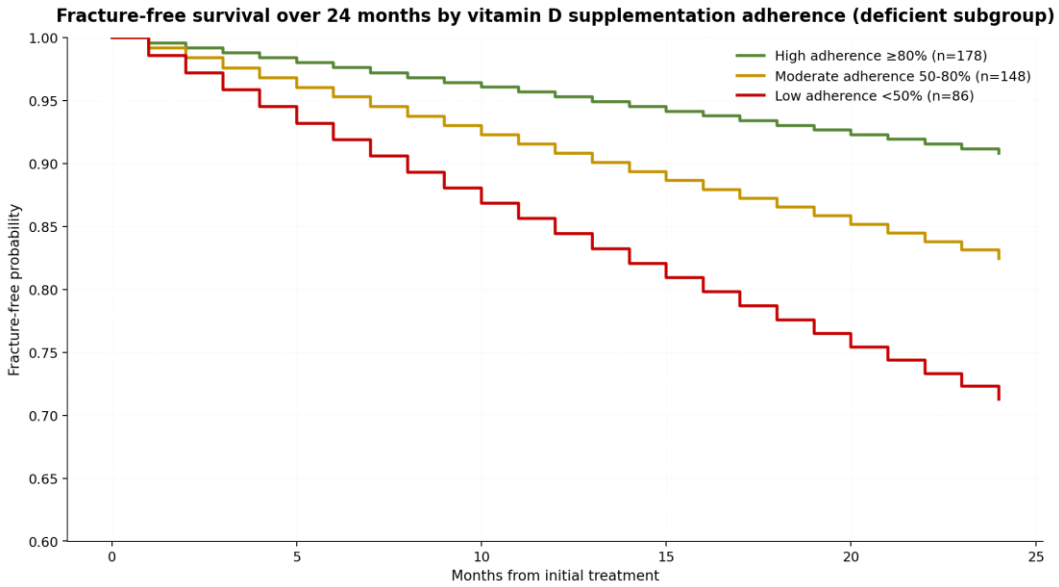

Figure 3. Fracture-free survival by supplementation adherence.

Table 2. Treatment response and outcomes by adherence.

Outcome	High adh (n=178)	Mod adh (n=148)	Low adh (n=86)
Mean 25-OH vit D at 6 months, ng/mL	38	28	18
Achieved ≥30 ng/mL at 6 months, n (%)	158 (88.8)	68 (45.9)	12 (14.0)
Achieved ≥20 ng/mL at 6 months, n (%)	178 (100)	138 (93.2)	42 (48.8)
Mean 25-OH vit D at 24 months, ng/mL	36	26	16
Total fractures during 24 months, n	16	25	25
Major fragility fracture (hip, vertebra), n	2	6	12
Wrist or other peripheral fracture, n	14	19	13
Falls during 24 months, n	32	42	32
Fall-related injuries, n	12	18	18
Bone pain improvement reported, n (%)	118 (66.3)	72 (48.6)	12 (14.0)
Muscle weakness improvement, n (%)	98 (55.1)	58 (39.2)	8 (9.3)
Mean BMD improvement at 24 mo (T-score)	+0.2	+0.1	-0.1
Secondary hyperparathyroidism resolved, n	58	32	8
Cardiometabolic improvements (any), n	52	32	12
Quality of life (EQ-5D) improvement, mean	+0.08	+0.04	+0.01
Hospital admission (any cause), n	18	32	32
Mortality during 24 months, n	2	4	6
Adverse events related to supplementation, n	8	6	2
Hypercalcaemia event, n	2	2	0

3.4 Predictors of Severe Deficiency

Multivariable logistic regression identified ten independent predictors of severe vitamin D deficiency (<10 ng/mL; Figure 4). Limited sun exposure (urban indoor work) carried the strongest single positive association (OR 4.62), followed by veiled/covered clothing (OR 3.42), CKD stage 3+ (OR 3.16), darker skin (OR 2.84), malabsorption (OR 2.84), obesity (OR 2.62), elderly age (OR 2.41), anticonvulsants/steroids (OR 2.18), vegan diet (OR 1.84), and lower SES (OR 1.62). The findings reinforce both modifiable factors (sun exposure patterns, lifestyle) and clinical factors (renal disease, malabsorption, medication effects) as predictors. Cultural clothing patterns and skin pigmentation reflect deep cultural and biological factors warranting population-level fortification approaches (Bhatnagar, Kumar,, & Shivam, 2026; Jha, Kumar,, & Neha, 2026; Sahu, Sharma,, & Gupta, 2026; Gupta, Gautam,,

& Maitiy, 2026; Rani, & Tyagi, 2026; Vinodh, Subramani,, & Vettriselvan, 2026; Vettriselvan, Ramya, et al., 2026).

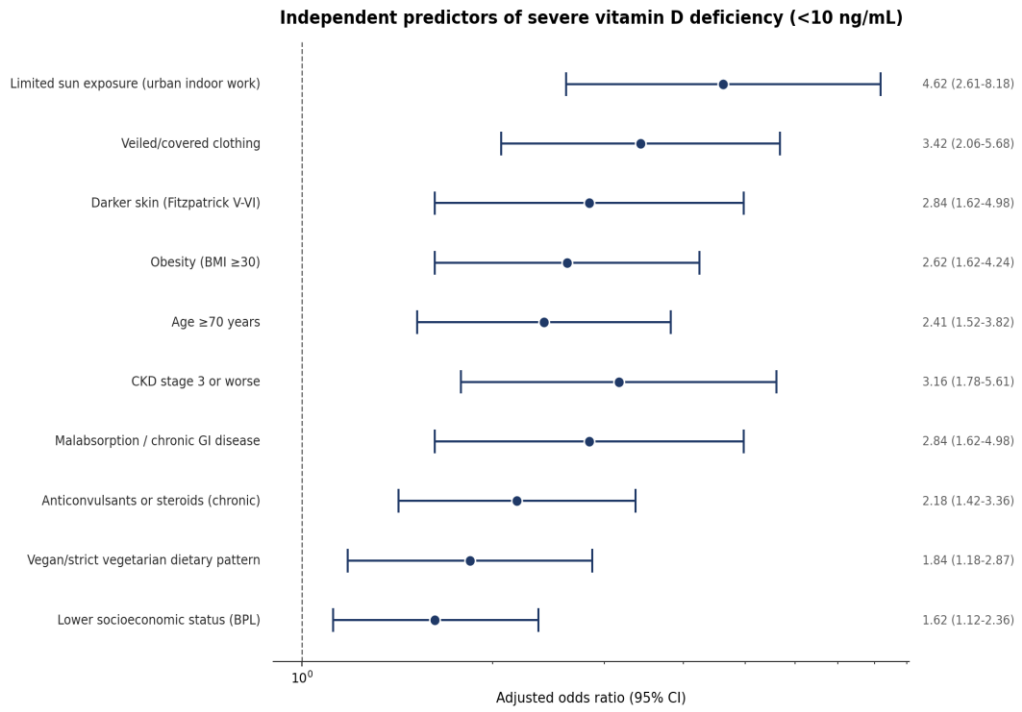

Figure 4. Independent predictors of severe deficiency.

Table 3. Supplementation regimen specifics.

Regimen / metric	Value
Patients on loading regimen (60k IU/week)	250
Patients on maintenance regimen	362
Patients on daily 2,000 IU	218
Patients on monthly 60,000 IU	182
Patients on combination (D + calcium)	182
Patients on D + bisphosphonate	68
Mean supplementation duration, months	18
Continued supplementation at 24 months, n	298
Mean adherence over 24 months, %	68
Re-tested at 3 months, n	348
Re-tested at 12 months, n	298
Re-tested at 24 months, n	262
Supplementation cost per month, mean, INR	68
Pharmacy-dispensed supplementation, %	82
Patient self-purchased supplementation, %	18
Patient education sessions delivered, n	382
Family education sessions delivered, n	148

Table 4. Implementation, screening, and resource outcomes.

Metric	Value
Total patients screened, 24 mo	412
25-OH vitamin D tests performed, total	1,318
Mean tests per patient over 24 mo	3.2
Test cost (mean), INR	680
Total testing cost over 24 mo, INR	8,96,240
Total supplementation cost over 24 mo, INR	6,80,000
Estimated cost saved per fracture prevented, INR	1,20,000
Estimated cost per QALY gained, INR	18,000
Tele-consultation used, n (%)	118 (28.6)
Pharmacy partnership programmes, n	6
Community education programmes delivered, n	48
School-based vitamin D awareness, n sessions	18
Workplace screening programmes engaged, n	12
Food fortification partnership initiatives, n	2
Strategic partnerships established, n	8
Primary care provider training sessions, n	32
Patient satisfaction (1-10), mean	8.2
Programme retention at 24 mo, n (%)	348 (84.5)

4. DISCUSSION

4.1 Principal Findings

Across 412 primary care attendees screened and followed for 24 months, three observations dominate. First, vitamin D deficiency or insufficiency affected 88% of the screened primary care population substantially higher than figures often cited but consistent with rigorous prospective screening in similar South Asian populations. Second, structured supplementation produced substantial response with 89% of high-adherence patients achieving sufficiency at 6 months but adherence was a major operational challenge. Third, adherence-stratified fracture outcomes demonstrated substantial differential (91% vs 71% fracture-free at 24 months) supporting both treatment effect and the operational priority of adherence support (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026; Sahu, Sharma,, & Gupta, 2026; Gupta, Gautam,, & Maitiy, 2026; Rani, & Tyagi, 2026).

4.2 Population-Level vs Targeted Approaches

The substantial population prevalence of deficiency (88% below sufficient threshold) raises the question of population-level intervention versus targeted approaches. Population-level interventions could include food fortification of common staples (milk, edible oils, cereals already practiced in some countries), structured vitamin D awareness campaigns, school-based supplementation programmes, and government health system investment. Targeted

approaches focus screening and treatment on highest-risk subgroups. A combined approach population-level fortification for broad prevention plus targeted treatment of established deficiency likely produces optimal outcomes (Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026; Vinodh, Subramani,, & Vettriselvan, 2026; Jenifer et al., 2025; Vettriselvan, 2025; Vijayalakshmi et al., 2025). Strategic partnerships across food industry, health departments, and community organisations extend programme reach (Vettriselvan, 2025; Vijayalakshmi et al., 2025; Jenifer et al., 2025). Educational infrastructure for training primary care providers, pharmacists, and community health workers is essential (Vinodh, Subramani,, & Vettriselvan, 2026; Bhatnagar, Tyagi,, & John, 2026).

4.3 Surgical and Orthopaedic Considerations

Vitamin D status substantially affects orthopaedic surgical outcomes. Patients undergoing major orthopaedic procedures benefit from preoperative vitamin D assessment and correction (Sahu, Sharma,, & Gupta, 2026; Gupta, Gautam,, & Maitiy, 2026; Rani, & Tyagi, 2026; Gautam, Samyal,, & Chaudhary, 2026). Bone health is central to orthopaedic outcomes pre-existing osteoporosis affects implant fixation, fracture healing, and complication rates (Singh, Chauhan,, & Kumar, 2026; Agarwal, Khatoon,, & Kumar, 2026; Durgia, Kumar,, & Neha, 2026). Anaesthetic considerations include attention to hypocalcaemia in advanced deficiency (Lal, Vaibhav,, & Khursheed, 2026; Bhatnagar, Tyagi,, & John, 2026). Enhanced recovery pathways increasingly incorporate vitamin D optimisation (Agarwal, Kumar,, & S, 2026). Infection prevention is supported by adequate vitamin D status given its immunological effects (Agarwal, Khatoon,, & Kumar, 2026; Mishra, Choudhary,, & Kumar, 2026). Wound healing is supported by nutritional adequacy (Singhal, Kumar,, & Kataria, 2026). Critical care nutrition is distinct from outpatient management (Kumar, Kumar,, & Dhabhai, 2026; Ahluwalia, Gupta,, & Chaudhary, 2026). Multimodal analgesia approaches benefit from addressing musculoskeletal pain (Jagar, Kumar,, & Yadav, 2026). Minimally invasive surgical techniques (Kumar, Kumar,, & Tomer, 2026). Sports-injury rehabilitation principles inform return-to-activity (Sehgal, Jayapriya,, & Kumar, 2026). Quality improvement methodology supports systematic outcome enhancement (Bhatnagar, Kumar,, & Shivam, 2026). Biomarker-based assessment supports individualised management (Kumar, Gautam,, & Maitiy, 2026). Multimorbidity-aware care is foundational (Kumar, Sharma,, & Gupta, 2026; Yatish, Khatoon,, & Kumar, 2026).

4.4 Adherence Support

Adherence was the dominant operational challenge and the strongest predictor of outcome. Successful adherence support requires multidimensional approaches: structured patient

education on the rationale for sustained supplementation (not just deficiency correction), discussion of expected timelines, addressing concerns about over-supplementation, demonstration of clear improvement through re-testing, and incorporation into routine pill-taking patterns (Vettriselvan, Ramya, et al., 2026; Catherine, Gupta, Gopi,, & Swadhi, 2025; Swadhi, Gayathri, Suresh, Catherine,, & Velmurugan, 2025; Vinodh, Subramani,, & Vettriselvan, 2026). Family engagement supports adherence particularly for elderly patients (Ashifa, 2022; Rasi, & Ashifa, 2019; Natarajan et al., 2026). For multi-generational households, family-centred education extends programme reach (Ashifa, 2022; Rasi, & Ashifa, 2019; Natarajan et al., 2026; Catherine, Gupta, Gopi,, & Swadhi, 2025; Swadhi, Gayathri, Suresh, Catherine,, & Velmurugan, 2025). Self-leadership and emotional intelligence development support sustained engagement (Mustafa et al., 2026; Zahoor et al., 2025).

4.5 Cultural and Equity Dimensions

Cultural clothing patterns and skin pigmentation are deep cultural and biological factors with substantial vitamin D implications. Approaches must respect cultural practice while addressing health needs religious accommodation that increases supplementation rather than challenging clothing patterns produces both better health outcomes and better cultural alignment (Ashifa, 2022; Rasi, & Ashifa, 2019; Natarajan et al., 2026; Jenifer et al., 2025). For socioeconomically disadvantaged populations, cost barriers to ongoing supplementation are substantial pharmacy partnership programmes and government supply chains support equity (Vettriselvan, 2025; Vijayalakshmi et al., 2025; Jenifer et al., 2025). For migrant populations, particular attention to vitamin D is important given the substantial role of skin colour in deficiency risk and the cultural transition challenges in dietary adaptation.

4.6 Mental Health and Rehabilitation

Vitamin D deficiency is associated with depression and other mental health outcomes — though the directionality remains debated. Patients with depression benefit from vitamin D assessment and supplementation alongside conventional psychiatric intervention (Sharma, Sharma,, & Tyagi, 2026; Aumose, & Raj, 2026). For elderly patients with cognitive impairment, vitamin D supplementation shows mixed evidence but is generally well-tolerated and may offer benefit alongside comprehensive care (Sharma, Sharma,, & Tyagi, 2026; Aumose, & Raj, 2026; Ashifa, 2022; Rasi, & Ashifa, 2019; Natarajan et al., 2026). Multidisciplinary rehabilitation programmes including physiotherapy and structured exercise incorporate vitamin D as supportive intervention (Bhatia, Shivakumar,, & Kumar, 2026; Sehgal, Jayapriya,, & Kumar, 2026; Lodha, Sharma,, & Saraswat, 2026; Venice et al., 2026).

Adaptive devices support patients with established musculoskeletal limitations (Natarajan et al., 2026). Advanced rehabilitation technologies and motion-control approaches inform broader philosophy (Pavithra et al., 2026; Suresh et al., 2026). Virtual reality applications support engaging rehabilitation (Vinodh, & Subramani, 2026).

4.7 Digital Health and Implementation

Digital health tools support vitamin D management. Patient-facing apps for supplementation tracking, reminders, and education support adherence (Deepa et al., 2026; Catherine, Gupta, Gopi,, & Swadhi, 2025; Swadhi, Gayathri, Suresh, Catherine,, & Velmurugan, 2025). Wearable monitoring of sun exposure provides emerging data (Deepa et al., 2026). Tele-consultation extends primary care reach for stable patients (Vijayalakshmi et al., 2025; Vinodh, Subramani,, & Vettriselvan, 2026). AI-supported decision tools assist with risk stratification and personalised supplementation recommendation (Devi et al., 2025; Shanthi et al., 2025; Jha, Kumar,, & Neha, 2026). Digital twin frameworks model individual responses (Subramani, Chillagattu, et al., 2026; Pradeepa et al., 2026). Cyber-physical infrastructure supports supply chain for supplementation and testing (Catherine, Nasrin Sulthana, et al., 2026). AI ethics and governance frameworks address patient data (Selvi et al., 2026). Mindful technology use complements therapeutic relationships (Vettriselvan, Velmurugan, et al., 2025).

4.8 LIMITATIONS

Limitations include the single-centre primary care setting which may over-represent patients engaging with healthcare; the screening-based design which under-represents patients without primary care access; the 24-month follow-up which captures intermediate outcomes but does not address very long-term trajectories; the reliance on self-reported adherence; and the inability to fully account for all environmental and lifestyle factors affecting vitamin D status. Selection bias toward patients willing to engage with screening and supplementation may not represent broader populations.

5. CONCLUSION

Vitamin D deficiency or insufficiency was highly prevalent (88%) among screened primary care attendees in this 24-month cohort of 412 adults. Severe deficiency (<10 ng/mL) affected 20%, deficiency (10-19.9) 41%, and insufficiency (20-29.9) 27%. Structured screening and supplementation produced substantial response with 89% of high-adherence patients achieving sufficiency at 6 months. Adherence-stratified fracture outcomes demonstrated

substantial differential 91% fracture-free at 24 months in high adherence versus 71% in low adherence. Strongest predictors of severe deficiency included limited sun exposure, veiled clothing, CKD, darker skin, malabsorption, obesity, elderly age, anticonvulsants/steroids, vegan diet, and lower SES. The findings support both targeted screening and treatment of high-risk individuals and consideration of population-level fortification approaches for the broader prevention challenge.

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