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Effectiveness of Vitamin D supplementation in improving health outcomes among school-going children: A systematic review

Swati Pandey[1], Cheenam Bhatia[2], Basabi Barari Dhar[3], Souvik Tewari[4], Sadhni Induar[5*]
[1] IGNOU, KPC Medical College and Hospital, West Bengal, India
[2] Senior Dietician, SGRD University of Health Sciences, Punjab, India
[3] Professional Diploma in Nutrition and Diet Planning, FSTN Exploration Foundation, West Bengal, India
[4] Assistant Professor, Department of Food and Nutrition, Swami Vivekananda University, Barrackpore, West Bengal, India
[5] Assistant Professor, Department of Food Science and Technology, School of CIST, KISS-DU, Odisha, India
Corresponding Author: Sadhni Induar

Abstract
Vitamin D is an essential micronutrient involved in calcium and phosphorus metabolism, skeletal development, immune regulation, muscle function, and several cellular processes important during childhood and adolescence. School-going children represent a particularly important population for maintaining adequate vitamin D status because this period is characterized by rapid growth, increasing skeletal mineralization, physical activity, and exposure to infectious diseases. Vitamin D insufficiency and deficiency are common among children worldwide and may result from inadequate dietary intake, limited sunlight exposure, increased adiposity, rapid growth, skin pigmentation, and lifestyle factors. The effectiveness of vitamin D supplementation in improving health outcomes among school-going children has been investigated in randomized controlled trials and systematic reviews, although findings vary according to baseline vitamin D status, dosage, duration, season, and health outcome assessed. Recent evidence indicates that supplementation is effective in increasing serum 25-hydroxyvitamin D [25(OH)D] concentrations and may provide benefits for respiratory health, particularly during periods of low vitamin D status or limited ultraviolet-B exposure. A 2025 randomized trial among 6–8-year-old children reported fewer acute respiratory tract infection-related sick days following daily vitamin D supplementation, whereas a large three-year trial among South African schoolchildren found substantial improvement in vitamin D status but no significant effects on growth, body composition, pubertal development, or spirometric outcomes. Similarly, recent evidence suggests that supplementation does not necessarily improve bone mineral outcomes in otherwise healthy children when baseline vitamin D status is adequate. Therefore, vitamin D supplementation appears most beneficial when used to prevent or correct deficiency rather than as a universal intervention for improving all aspects of child health. Future research should focus on population-specific supplementation strategies, baseline vitamin D status, optimal dosing, long-term health outcomes, and children at particularly high risk of deficiency.

Keywords: Vitamin D, school-going children, vitamin D deficiency, 25-hydroxyvitamin D, supplementation, growth, immunity, respiratory infections, bone health, child nutrition

Introduction
Vitamin D is a fat-soluble hormone-like vitamin that plays a fundamental role in calcium and phosphorus homeostasis and is essential for normal skeletal growth and development. In children, vitamin D is particularly important because childhood and adolescence are periods of rapid bone accretion, during which adequate mineral availability is necessary for achieving optimal peak bone mass. Beyond its classical skeletal functions, vitamin D receptors are present in numerous tissues, suggesting roles in immune regulation, muscle function, cellular differentiation, and inflammatory responses. Vitamin D status is generally assessed using circulating serum 25(OH)D concentration, which reflects vitamin D obtained through cutaneous synthesis and dietary or supplemental sources. The importance of adequate vitamin D status has increased because modern lifestyles may reduce sunlight exposure and because dietary sources of vitamin D are relatively limited (Alam *et al*., 2025) [1]. Recent evidence synthesized for the Endocrine Society's 2024 [11] clinical practice guideline indicates that vitamin D supplementation may have selected benefits in children and adolescents, particularly regarding respiratory tract infections, although the certainty of evidence varies among outcomes (Shah *et al*., 2024) [11].

Vitamin D Status and Deficiency among School-Going Children
Vitamin D deficiency and insufficiency can occur during school age because of inadequate dietary intake, insufficient exposure to sunlight, increased skin pigmentation, indoor lifestyles, obesity, rapid growth, and geographic or seasonal differences in ultraviolet-B exposure. Children living at higher latitudes may be particularly vulnerable during winter, whereas children in countries with abundant sunlight may also develop deficiency because of indoor lifestyles, clothing practices, air pollution, or inadequate dietary intake. In India, vitamin D deficiency is considered an important public health concern despite substantial environmental availability of sunlight. A 2025 Indian expert consensus emphasized the high prevalence of vitamin D deficiency and highlighted the need for age-specific strategies for prevention and treatment, while also noting inconsistencies in definitions and thresholds used across clinical guidelines (Kalra *et al*., 2025) [5]. Thus, school-based nutritional assessment and targeted supplementation may be particularly relevant for children with limited sun exposure, inadequate dietary intake, or laboratory-confirmed deficiency.

Biological Role of Vitamin D in Childhood

The biological activity of vitamin D begins with conversion of vitamin D to 25(OH)D in the liver and subsequent conversion to the biologically active metabolite 1,25-dihydroxyvitamin D in the kidney and other tissues. Active vitamin D promotes intestinal absorption of calcium and phosphorus and contributes to bone mineralization and maintenance of calcium homeostasis (Bikle, 2014) [2]. Vitamin D receptors are also expressed in immune cells, skeletal muscle, and various other tissues, providing a biological basis for effects beyond bone health. Adequate vitamin D availability during childhood is therefore important for maintaining normal skeletal development while potentially supporting immune and muscular functions. However, the presence of vitamin D receptors in multiple tissues does not necessarily mean that supplementation above adequate physiological levels improves every health outcome. Recent evidence emphasizes that clinical benefits are influenced by baseline vitamin D status and the characteristics of the population receiving supplementation (Shah *et al*., 2024) [11].

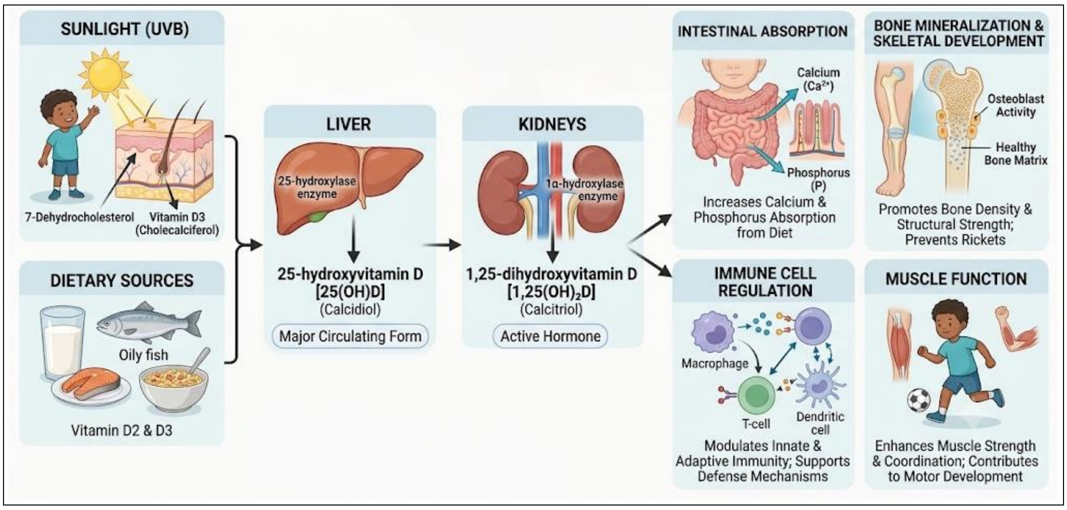

Fig 1: Visualizing the Biological Pathway and Multi-System Roles of Vitamin D in Childhood Development (Shah *et al*., 2024) [11].

Vitamin D Supplementation and Bone Health

Bone health is one of the most established areas in which vitamin D has biological importance during childhood. Adequate vitamin D facilitates calcium absorption and supports mineralization of growing bone, while severe deficiency can contribute to rickets and impaired skeletal development. However, evidence from supplementation trials indicates that increasing vitamin D concentrations above adequate levels does not necessarily produce additional improvements in bone mineralization among healthy schoolchildren (Winzenberg *et al*., 2011) [15].

The large ViDiKids randomized controlled trial conducted among 1,682 South African schoolchildren aged 6–11 years demonstrated that three years of weekly vitamin D3 supplementation substantially increased serum 25(OH)D concentrations, but did not significantly alter bone mineral content or related skeletal outcomes compared with placebo. These findings suggest that correcting deficiency is likely more important for skeletal health than indiscriminate high-dose supplementation in children who already have adequate vitamin D status (Middelkoop *et al*., 2024a) [6].

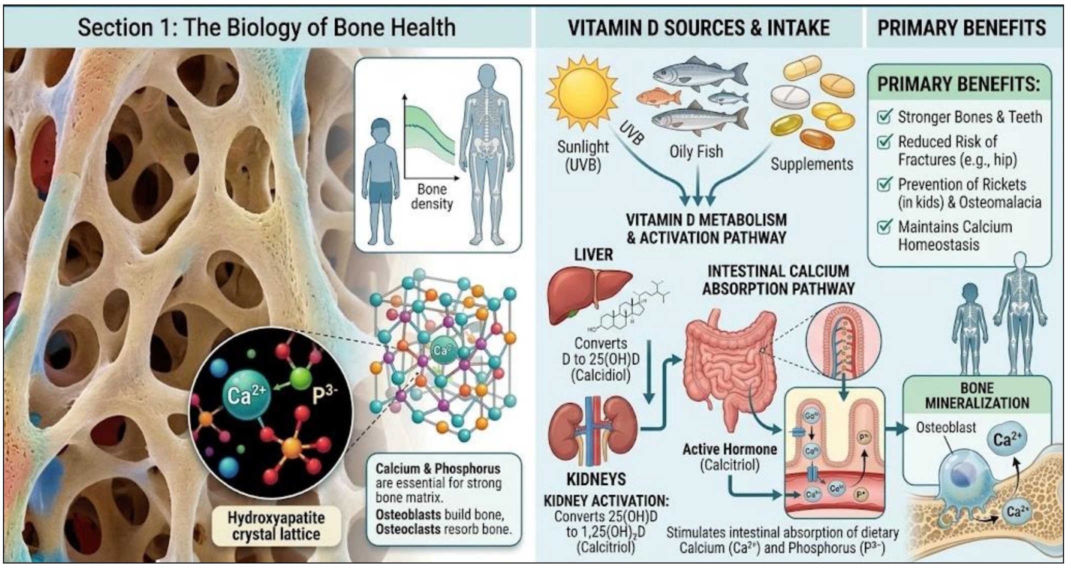

Fig 2: The Multi-System Effects of Vitamin D on Bone, Muscle, and Immune Health (Urashima *et al*., 2018) [13].

Vitamin D Supplementation and Growth

Growth during school age is influenced by genetic, nutritional, hormonal, environmental, and socioeconomic factors. Vitamin D may indirectly support normal growth by facilitating calcium and phosphorus metabolism and maintaining skeletal health. Nevertheless, evidence that supplementation directly increases height or improves anthropometric growth in generally healthy schoolchildren remains inconsistent. The ViDiKids trial, which followed 1,682 children for three years, found no significant difference in height-for-age z-score or BMI-for-age z-score between children receiving 10,000 IU vitamin D3 weekly and those receiving placebo. The intervention also did not significantly influence body composition or pubertal development (Middelkoop *et al*., 2024b) [6]. These findings indicate that vitamin D supplementation should not be regarded as a stand-alone growth-promoting intervention when children already have adequate vitamin D levels and access to an otherwise sufficient diet.

Vitamin D and Immune Function

Vitamin D has attracted considerable attention for its potential immunomodulatory effects. Immune cells can metabolize vitamin D, and vitamin D signaling may influence innate and adaptive immune responses, antimicrobial peptide production, and inflammatory pathways. These mechanisms have generated interest in vitamin D supplementation as a strategy for reducing childhood infections. Nevertheless, biological plausibility does not consistently translate into clinically meaningful reductions in infection incidence. A 2024 systematic review supporting the Endocrine Society guideline found low-certainty evidence suggesting a reduction in respiratory tract infections among children and adolescents receiving empiric vitamin D supplementation (Shah *et al*., 2024) [11]. Therefore, the potential immune benefits appear promising but should be interpreted in the context of baseline vitamin D status, season, dose, and the specific infectious outcome being studied.

Vitamin D Supplementation and Respiratory Infections

Respiratory infections are among the most common causes of illness and school absenteeism in children, making prevention particularly relevant to school health programs. Recent clinical evidence provides support for a possible protective effect of vitamin D in selected populations. In a randomized clinical trial involving healthy 6–8-year-old children, daily supplementation with 20 µg vitamin D3 during an extended winter period resulted in 17% fewer sick days due to acute respiratory tract infections and 43% fewer days with respiratory infection accompanied by fever compared with placebo (Clerico *et al*., 2025) [3]. However, broader evidence remains heterogeneous. A 2024 systematic review and dose-response meta-analysis involving 43 randomized controlled trials and 49,320 participants found no significant overall preventive effect of vitamin D supplementation on acute respiratory infection incidence, although daily supplementation and winter-dominant interventions showed potentially beneficial effects in subgroup analyses (Wang *et al*., 2024) [14]. These findings suggest that supplementation may be more effective in specific seasonal or deficient populations rather than universally preventing respiratory infections.

Effect on Frequency and Severity of Infections

The effect of vitamin D supplementation may extend beyond the occurrence of infection to the frequency and severity of illness. A 2025 review of pediatric studies reported that children experiencing viral upper respiratory tract infections frequently had lower vitamin D concentrations and that several supplementation studies observed reductions in respiratory infections, although results were not uniformly positive. Importantly, the review indicated that higher doses were not consistently superior to lower doses and that very high supplementation may not provide additional benefit (Devulapalli, 2025) [4]. Similarly, a 2024 pediatric observational study reported substantially lower respiratory infection incidence among children receiving higher weekly vitamin D supplementation and among those with serum 25(OH)D concentrations above 30 ng/mL; however, because of its cross-sectional design, the findings cannot establish causality (Tanase *et al*., 2024) [12]. Collectively, these findings support further investigation while emphasizing that vitamin D should not replace established infection-prevention measures such as vaccination, hand hygiene, adequate nutrition, and appropriate medical care.

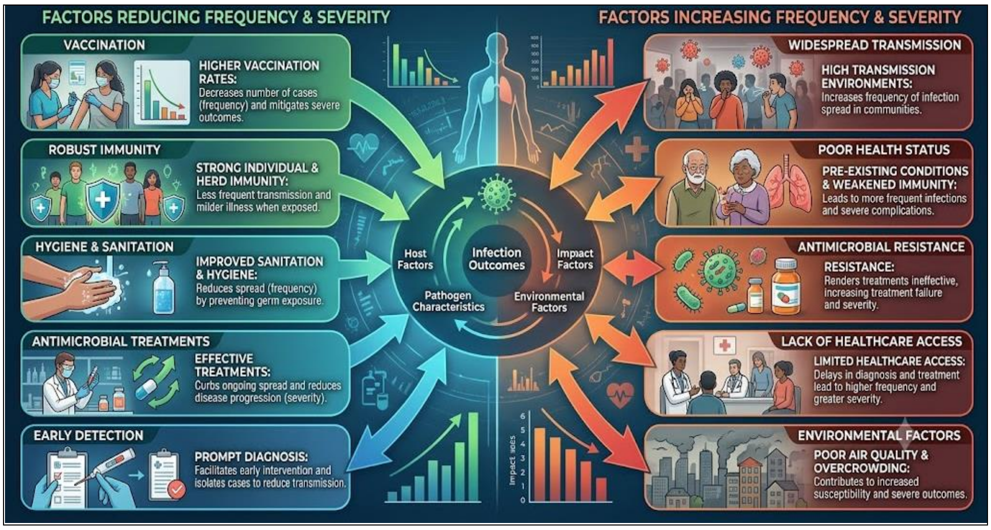

Figure 3: Factors Influencing the Frequency and Severity of Infectious Diseases (Winzenberg *et al*., 2011) [15].

Vitamin D, Physical Performance and Musculoskeletal Health

Vitamin D is also relevant to skeletal muscle function and physical performance during school age. Adequate vitamin D contributes to normal muscle physiology, and deficiency has been associated with muscle weakness in severe cases. Nevertheless, clinical evidence for supplementation improving physical performance in healthy schoolchildren remains limited. In the ViDiKids trial, long-term vitamin D supplementation did not produce meaningful improvements in growth-related or body-composition outcomes, suggesting that raising serum 25(OH)D concentrations alone does not necessarily translate into broad functional improvements in healthy children (Middelkoop *et al*., 2024b) [6]. Consequently, vitamin D supplementation should be considered as one component of nutritional adequacy rather than a substitute for regular physical activity, adequate protein and mineral intake, sleep, and overall healthy lifestyle practices.

Vitamin D and Cognitive or Neurodevelopmental Outcomes

Vitamin D has been investigated in relation to brain development and cognitive function because vitamin D receptors and vitamin D metabolic enzymes are present in neural tissues. However, evidence supporting supplementation as a strategy for improving cognition or academic performance in school-going children remains insufficient. The biological association between vitamin D and neurodevelopment does not establish that supplementation in vitamin-D-replete children will improve cognitive outcomes. Recent systematic evidence has primarily supported clearer benefits for correcting deficiency and selected respiratory outcomes rather than demonstrating consistent improvements in cognition among healthy children (Shah *et al*., 2024) [11]. Future randomized trials should include standardized measures of cognitive performance, school attendance, academic outcomes, and baseline vitamin D status before conclusions can be drawn regarding educational benefits.

Dose, Frequency and Duration of Supplementation

The effectiveness of vitamin D supplementation depends strongly on dose, frequency, duration, season, baseline vitamin D status, age, body size, and the presence of underlying conditions. A 2024 [11] systematic review examining optimal supplementation strategies for respiratory infection prevention found that daily dosing in the range of approximately 400–1,200 IU/day was associated with potentially beneficial effects in selected seasonal subgroups, while the overall effect across all trials was not statistically significant (Wang *et al*., 2024) [14]. In children with symptomatic deficiency, an Indian randomized controlled trial comparing daily and fortnightly vitamin D3 regimens found both regimens effective in restoring serum 25(OH)D concentrations and improving biochemical markers of deficiency, although transient hypercalcemia occurred in some participants (Mondal *et al*., 2024) [10]. These findings emphasize that supplementation should follow age-appropriate recommendations and clinical indications rather than using high-dose regimens indiscriminately.

Safety Considerations

Vitamin D is generally safe when administered at appropriate doses, but excessive intake can result in hypercalcemia, hypercalciuria, gastrointestinal symptoms, renal complications, and other manifestations of vitamin D toxicity. Safety is particularly important when intermittent high-dose preparations are used in children. In the randomized Indian trial of children aged 1–10 years with symptomatic deficiency, both daily and fortnightly treatment were effective, but transient asymptomatic hypercalcemia occurred in some participants (Mondal *et al*., 2024) [10]. Therefore, supplementation programs should distinguish between routine nutritional supplementation and therapeutic treatment of documented deficiency. Children requiring pharmacological doses should preferably be managed according to age-specific clinical guidance, with monitoring where clinically indicated.

Evidence from Recent Randomized Controlled Trials

Recent randomized controlled trials demonstrate why the effects of vitamin D supplementation should be interpreted according to the outcome being assessed. In the three-year ViDiKids trial, weekly vitamin D3 substantially increased serum 25(OH)D but did not significantly improve height, BMI, body composition, pubertal development, or spirometry (Middelkoop *et al*., 2024b) [6]. A related ViDiKids analysis also found no meaningful improvement in bone mineral content or other skeletal outcomes despite improved vitamin D status (Middelkoop *et al*., 2024a). Conversely, the 2025 [4, 6] Danish trial found significantly fewer acute respiratory infection-related sick days among children receiving daily vitamin D during winter (Clerico *et al*., 2025) [3]. Thus, current evidence suggests that vitamin D supplementation reliably improves biochemical vitamin D status, while clinical benefits are outcome- and population-dependent.

Relevance to School Health and Nutrition Programs

School health programs provide an important platform for identifying children at risk of micronutrient deficiencies and promoting healthy dietary and lifestyle behaviors. Vitamin D interventions may be particularly relevant in populations where deficiency is common or where children have limited exposure to sunlight. However, universal supplementation should be carefully considered because the magnitude of benefit depends on baseline status and the population's risk profile. In India, the 2025 [5] expert consensus highlighted the substantial burden of vitamin D deficiency and provided population-specific recommendations for prevention and treatment, including recommendations for children and adolescents (Kalra *et al*., 2025) [5]. School-based strategies should therefore ideally integrate nutritional education, safe outdoor physical activity, dietary sources of vitamin D and calcium, identification of high-risk children, and referral for clinical evaluation when deficiency is suspected.

Research Gaps and Future Directions

Despite increasing evidence, several important questions remain unanswered. Future trials should stratify participants according to baseline serum 25(OH)D concentrations, because children who are deficient may respond differently from vitamin-D-replete children. Studies should also investigate age-specific doses, seasonal supplementation, adherence, obesity status, dietary calcium intake, sun exposure, skin pigmentation, socioeconomic factors, and long-term outcomes. More research is needed to establish whether supplementation affects school attendance, academic performance, respiratory morbidity, physical fitness, bone strength, and quality of life. The heterogeneity of existing studies also emphasizes the need for standardized definitions of deficiency, consistent outcome measures, and adequately powered randomized controlled trials. Current evidence suggests that supplementation is most defensible as a strategy to prevent or correct inadequate vitamin D status rather than as a universal treatment expected to improve every aspect of child health.

Table 1: Summary of Previous Studies on the Effectiveness of Vitamin D Supplementation in Improving Health Outcomes among School-Going Children

Author(s), Year	Study population & sample size	Vitamin D intervention	Major health outcome assessed	Key findings
Middelkoop *et al*. (2024a) [6]	1,682 schoolchildren, 6–11 years	Vitamin D_3 10,000 IU/week vs. placebo	Bone mineral content, bone turnover and fractures	Vitamin D significantly increased serum 25(OH)D and reduced PTH, but did not significantly improve whole-body or lumbar-spine bone mineral content. Fractures were uncommon.
Middelkoop *et al*. (2024b) [6]	1,682 schoolchildren, 6–11 years	Vitamin D_3 10,000 IU/week vs. placebo	Growth, BMI, body composition, puberty and lung function	Serum 25(OH)D increased substantially in the supplementation group; however, there were no significant differences in height-for-age, BMI-for-age, body composition, pubertal development or spirometric measures.
Clerico *et al*. (2025) [3]	200 healthy children, 6–8 years	Vitamin D_3 20 µg/day (800 IU/day) vs. placebo	Acute respiratory tract infections (ARTI)	Children receiving vitamin D had 17% fewer ARTI-related sick days and 43% fewer days with ARTI accompanied by fever compared with placebo.
Mondal *et al*. (2024) [10]	80 children with symptomatic vitamin D deficiency, 1–10 years	4,000 IU/day vs. 60,000 IU every 2 weeks, with calcium	Correction of vitamin D deficiency, calcium-phosphorus metabolism and safety	Both regimens significantly improved serum 25(OH)D, calcium and phosphorus and reduced ALP and PTH. Both regimens achieved vitamin D sufficiency. Transient asymptomatic hypercalcemia occurred in some children.
Wang *et al*. (2024) [14]	Randomized controlled trials of children and adults	Various vitamin D supplementation regimens	Acute respiratory infections	The meta-analysis found that effects varied according to dosing regimen, season and baseline vitamin D status; daily supplementation and some winter-dominant interventions showed potentially greater benefit.
Devulapalli (2025) [4]	Children with viral upper respiratory tract infections	Vitamin D supplementation in children with lower vitamin D concentrations	Viral upper respiratory tract infections	The review reported evidence that supplementation may reduce viral upper respiratory infection risk, particularly among children with lower vitamin D concentrations.

Table 2: Overall Evidence of Vitamin D Supplementation on Health Outcomes in School-Going Children

Health outcome	Evidence from previous studies	Effect of supplementation	Interpretation
Serum 25(OH)D concentration	Consistent across randomized trials	↑ Significant	Vitamin D supplementation reliably improves biochemical vitamin D status.
Bone mineral content	3-year ViDiKids RCT	No significant improvement	Additional supplementation may provide limited skeletal benefit when baseline status is adequate.
Growth/height	3-year ViDiKids RCT	No significant effect	Vitamin D alone does not appear to promote linear growth in vitamin-D-replete schoolchildren.
BMI/body composition	ViDiKids	No significant effect	Supplementation did not meaningfully alter BMI-for-age, fat mass or fat-free mass.
Pubertal development	ViDiKids	No significant effect	Long-term supplementation did not accelerate or delay measured pubertal outcomes.
Respiratory infections	Recent RCTs and meta-analyses	Mixed	Some trials show reduced illness/sick days, while pooled evidence remains inconsistent.
Respiratory infection-related sick days	Clerico *et al*. (2025) [3]	Significant reduction	Daily winter supplementation reduced ARTI-related sick days by 17%.
Fever-associated respiratory illness	Clerico *et al*. (2025) [3]	Significant reduction	Days with ARTI accompanied by fever were reduced by 43%.
Influenza infection	Vietnam RCT	No significant reduction	Vitamin D did not significantly prevent laboratory-confirmed influenza.
Non-influenza respiratory viruses	Vietnam RCT	Moderate reduction	Some evidence suggests protection against non-influenza respiratory viral infections.
Treatment of vitamin D deficiency	Indian RCT	Significant improvement	Both daily and fortnightly regimens successfully corrected symptomatic deficiency.
Parathyroid hormone (PTH)	ViDiKids bone-health study	Reduced	Supplementation improved vitamin D-related biochemical parameters.
Lung function	ViDiKids	No significant improvement	No meaningful improvement in FEV_1, FVC or FEV_1/FVC was observed.
Fracture risk	ViDiKids	Inconclusive	Fractures were rare, limiting statistical power to determine a protective effect.

Conclusion

Vitamin D plays a critical physiological role in skeletal development, calcium metabolism, muscle function, and immune regulation during childhood. Evidence from recent studies indicates that vitamin D supplementation effectively increases serum 25(OH)D concentrations and may reduce respiratory infection-related morbidity in selected school-going populations, particularly during winter or among children with inadequate vitamin D status. However, supplementation has not consistently demonstrated improvements in growth, body composition, pubertal development, lung function, or bone mineral outcomes among generally healthy schoolchildren with adequate baseline vitamin D status. Recent systematic reviews further indicate that the effects on respiratory infections are heterogeneous and may depend on dose, frequency, season, and baseline nutritional status. Therefore, the greatest value of vitamin D supplementation appears to lie in preventing and treating deficiency and targeting children at increased risk rather than indiscriminate high-dose supplementation. School nutrition and health programs should adopt a comprehensive approach combining adequate dietary intake, appropriate sunlight exposure, physical activity, calcium adequacy, nutritional education, and evidence-based vitamin D supplementation where indicated. Further well-designed, long-term randomized trials are needed to determine the population groups, doses, seasons, and clinical outcomes for which vitamin D supplementation provides the greatest health benefit.

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