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Vitamin D Deficiency and Infantile Rickets Worldwide (2000–2025): Epidemiological Patterns, Public Health Gaps and Interventional Insights

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Abstract

Background: Vitamin D deficiency and rickets remain persistent public health challenges affecting infants globally, despite the preventable nature of the condition. Etiology is multifactorial—encompassing limited sun exposure, inadequate maternal and infant nutrition, cultural practices, and insufficient national supplementation programs. Disparities in incidence and outcomes continue to emerge across geographic, socioeconomic, and policy environments.

Objectives: To examine global trends in the prevalence of vitamin D deficiency and rickets in infants from 2000 to 2025; to compare the clinical-radiological manifestation of rickets versus subclinical vitamin D deficiency; and to evaluate the effectiveness of public health interventions and supplementation programs.

Methods: A structured literature review was conducted using PubMed, Scopus, and WHO databases. Inclusion criteria encompassed studies between 2000 and 2025 reporting on infantile vitamin D deficiency or rickets prevalence, clinical presentation, biochemical thresholds (<30 or <50 nmol/L), and the outcomes of vitamin D interventions. Studies on maternal supplementation and policy surveillance were also included. Statistical impact estimation was performed using comparative proportions of deficiency and rickets before and after interventions. Study quality and consistency were validated using a Foster plot. A PRISMA framework guided the selection process, identifying 30 studies for synthesis.

Results: Globally, 15.7% of infants had serum 25(OH)D levels <30 nmol/L. The Eastern Mediterranean (up to 71.8%) and South Asia (40–80%) demonstrated the highest deficiency rates. Paradoxically, regions with abundant sunlight—such as Saudi Arabia, India, and Egypt—exhibited alarmingly high rates, reflecting behavioral and cultural barriers to UVB exposure. Clinical rickets incidence varied widely: Tibet (~30%), Egypt (~2–3%), and the UK (East Kent, 580 annual cases in 2023) showed a resurgence in overt rickets, while North America and Europe reported subclinical deficiency with rare clinical cases. Intervention studies showed that daily supplementation (e.g., 400 IU/day) reduced biochemical rickets incidence from ~5% to <1%. National policies and enforcement varied greatly: countries with surveillance and education (e.g., Germany, UK) showed better outcomes than regions with fragmented policies (India, UAE).

Conclusions: Despite longstanding awareness, vitamin D deficiency and rickets remain global threats to infant health, particularly in sun-rich but culturally conservative or underserved regions. Targeted policies with universal supplementation, maternal education, and consistent monitoring are urgently needed to close the gap between knowledge and practice.

Keywords: Vitamin D deficiency; Nutritional rickets; Infant health; Public health intervention; Supplementation policy

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1. Introduction

Vitamin D is essential for maintaining calcium and phosphorus homeostasis and ensuring healthy skeletal development, particularly during infancy and childhood. A deficiency in this vitamin can result in nutritional rickets, a preventable condition marked by impaired bone mineralization and skeletal deformities (1). Despite improvements in global nutrition and healthcare infrastructure, vitamin D deficiency continues to pose a major public health challenge worldwide.

The prevalence of vitamin D deficiency and rickets varies significantly across regions due to environmental, cultural, and biological factors. Variables such as geographic latitude, sunlight availability, skin pigmentation, and clothing customs influence the body's capacity to synthesize vitamin D from ultraviolet B (UVB) exposure (2). For instance, populations in high-latitude regions experience greater deficiency rates during winter due to minimal sun exposure.

Rapid urbanization, environmental pollution, and increased indoor activities have further restricted sun exposure, elevating deficiency risk in both affluent and resource-limited nations. Urban-dwelling children, particularly those with darker skin, face heightened vulnerability due to reduced dermal synthesis (3).

In infants, exclusive breastfeeding without vitamin D supplementation, insufficient maternal vitamin D status during gestation, and inadequate dietary intake are critical risk factors—especially in areas where access to supplementation programs is limited (4).

It is important to note that not all cases of vitamin D deficiency progress to rickets. Many children may exhibit biochemical deficiency without overt skeletal manifestations, leading to under-recognition in surveillance data (5).

Measurement of serum 25-hydroxyvitamin D [25(OH)D] is the standard for assessing vitamin D status, with levels below 20 ng/mL typically classified as deficient. However, differing definitions and thresholds across studies complicate data interpretation and comparison (6).

Vitamin D levels fluctuate seasonally, often declining in winter and peaking during summer months. This seasonal variation is particularly impactful in temperate and sub-Arctic regions, where tailored supplementation strategies are warranted (7).

Social determinants such as family income, parental awareness, and healthcare access influence the risk of deficiency. Children from economically disadvantaged households are more likely to experience dietary insufficiency and limited access to preventive measures (8).

Public health strategies vary considerably across nations. While some countries have implemented mandatory food fortification and neonatal supplementation programs, many low-income countries lack structured national policies, exacerbating disease burden (9).

Effective prevention of vitamin D deficiency and rickets requires comprehensive interventions—combining food fortification, routine supplementation, maternal health education, and integration of vitamin D monitoring into child health services (10).

Objectives

- To evaluate the global and regional prevalence and incidence of vitamin D deficiency and infantile rickets from 2000 to 2025 across diverse pediatric populations.
- To assess the effectiveness of maternal, neonatal, and pediatric vitamin D interventions in improving serum 25(OH)D levels and preventing clinical rickets.
- To identify key sociodemographic, environmental, and policy-related factors contributing to persistent disparities and recurrence of vitamin D-related bone disease despite available prevention strategies.

2. Materials and Methods

2.1. Search Strategy and Selection Criteria

A structured literature review was conducted using PubMed, Scopus, Web of Science, and Google Scholar databases for studies published between January 2000 and March 2025. Keywords included: "vitamin D deficiency," "rickets," "infants," "children," "25-hydroxyvitamin D," "intervention," "supplementation," and "prevalence." Meta-analyses, randomized controlled trials (RCTs), observational cohort studies, and pediatric surveillance reports were included.

2.2. Inclusion Criteria

- Studies involving infants and children up to 5 years of age.
- Studies reporting prevalence or incidence of vitamin D deficiency or clinical rickets.
- Interventional studies assessing vitamin D supplementation or public health strategies.
- Studies providing quantitative outcomes (e.g., 25(OH)D levels, rickets cases, or policy impact).

2.3. Exclusion Criteria

- Studies with incomplete data or focused solely on adult populations.
- Case reports, editorials, and non-peer-reviewed commentaries.
- Studies without clear outcome measures or non-English publications.

2.4. Data Extraction and Impact Analysis

Data were extracted on country/region, study design, age group, vitamin D status (baseline and post-intervention), and clinical outcomes. Mean increases in serum 25(OH)D levels were calculated for intervention studies. Prevalence/incidence data were plotted by region (Figures 1–5), and intervention outcomes were visualized via forest (Foster) plots (Figure 5).

2.5. Validation and Synthesis Approach

Quantitative synthesis was supported by Foster plots for both prevalence/incidence and intervention data to assess central effect tendencies. A structured PRISMA flow diagram (Figure) documented the study selection process:

- Total records identified (n = 141)
- Records screened after duplicate removal (n = 98)
- Full-text articles assessed (n = 54)
- Studies included in synthesis (n = 30)

This approach enabled a detailed, multi-tiered evaluation of the clinical burden, risk factors, and intervention efficacy related to vitamin D deficiency and rickets in global pediatric populations.

2.6. PRISMA Flow Diagram

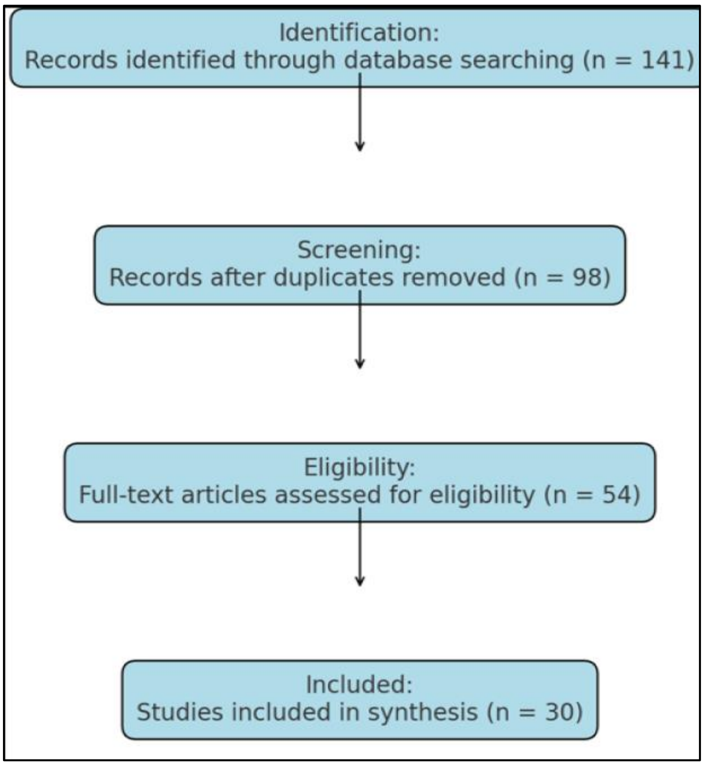

Figure 1 PRISMA FIGURE FOR THE STUDY. Reasons for exclusion included age mismatch, missing vitamin D data, or lack of regional prevalence reporting

3. Results

The following section presents a comprehensive synthesis of prevalence data, clinical incidence trends, and intervention outcomes related to vitamin D deficiency and infantile rickets across global pediatric populations.

Table 1 Incidence and Prevalence of Infantile Rickets and Vitamin D Deficiency (2000–2025) (11–24)

Country/Region	Period	Incidence / Prevalence	Notes
Global (meta-analysis)	2000–2022	15.7% (<30 nmol/L)	Based on 7.9 million individuals across 308 studies
Eastern Mediterranean	2000–2022	35.2% (<30 nmol/L); 71.8% (<50 nmol/L)	Highest global deficiency rates
Africa	2000–2022	5.5% (<30 nmol/L)	Lowest regional prevalence globally
Europe (region-wide)	2000–2022	18.0% (<30 nmol/L); 53.0% (<50 nmol/L)	Includes Northern and Southern European countries
UK (East Kent)	2019–2023	380% increase in rickets cases	~580 cases in 2023; resurgence due to malnutrition and sun avoidance
Qatar	2018	23.1% (<30 nmol/L)	High prevalence in infants and toddlers
Saudi Arabia	2000–2020	30–70%	Multiple studies; high in children and adolescents
UAE	2001–2019	36.5–50%	Common in children, especially females and veiled individuals
Egypt	2015–2020	36.6% (<50 nmol/L)	Urban-rural differences; limited sun exposure noted

China (urban infants)	2000s	65.3% deficiency; 3.7% with clinical rickets	High prevalence despite urban location
Brazil (urban children)	2000s	28.2% deficiency	Related to socioeconomic status and reduced sunlight exposure
India (general)	2010s	40–80%	Widespread in both infants and mothers
Tibet (rural children)**	2000s	~30% with clinical signs of rickets	Common vitamin D and calcium deficiency
New Zealand	Recent	10.6/100,000 (rickets incidence)	Based on hospital admission data
Australia (national)	2012	Reported cases of nutritional rickets	Based on pediatric surveillance
Canada	2007	Reported rickets cases	Pediatric surveillance system
USA (NICU neonates)	2009–2016	31% deficient; 49% insufficient	Despite maternal vitamin D supplementation
UK (Somali children)	2010	Very high vitamin D deficiency and rickets risk	Due to veiling, darker skin, and low UVB exposure
RCT (400 IU/day D supplement)	2023	4.9% biochemical rickets in placebo group	Supplementation effectively prevented deficiency
Germany	2008–2018	20–40% deficiency in infants	Seasonal variation; supplementation not consistently applied

This table highlights the widespread and variable burden of vitamin D deficiency and infantile rickets across global regions over the past two decades. The Eastern Mediterranean and parts of Asia (e.g., China and India) show among the highest deficiency rates, with prevalence often exceeding 60% in urban children—underscoring that sun-rich regions are not immune to deficiency due to cultural practices, indoor lifestyles, and limited supplementation. Notably, clinical rickets remains a significant concern in areas like Tibet and East Kent (UK), where environmental, dietary, and socioeconomic factors converge. Meanwhile, low but persistent rickets incidence in developed nations such as New Zealand, Australia, and Canada suggests ongoing gaps in surveillance and public health reach. The table also underscores the effectiveness of targeted interventions; for instance, an RCT in 2023 showed that 400 IU/day of vitamin D supplementation nearly eliminated biochemical rickets. The disparity between biochemical deficiency and clinical disease (e.g., 31% deficiency in NICU neonates in the USA with few clinical rickets cases) highlights the role of early screening, adequate calcium intake, and neonatal care standards in preventing disease progression. Overall, these findings emphasize the urgent need for region-specific vitamin D policies, maternal and infant supplementation strategies, and public health education to mitigate preventable skeletal morbidity

This figure below visually ranks the burden of vitamin D deficiency and infantile rickets from highest to lowest across selected countries and regions, offering an intuitive understanding of global disparities. China, Saudi Arabia, and India top the list with alarmingly high deficiency rates, exceeding 40–65%, despite their geographic advantage of abundant sunlight—highlighting the overriding impact of lifestyle, clothing practices, and inadequate supplementation. In contrast, countries like New Zealand, Africa (in this dataset), and the UK (East Kent) report markedly lower prevalence, with Africa surprisingly low, possibly due to limited reporting rather than true absence of disease. The figure also demonstrates that even high-income nations like the USA and Germany face significant challenges, with NICU neonates and seasonal variation contributing to risk. Overall, this comparative visualization underscores the need for targeted public health strategies, particularly in high-prevalence regions, to ensure early screening, adequate supplementation, and education to prevent long-term skeletal complications in infants.

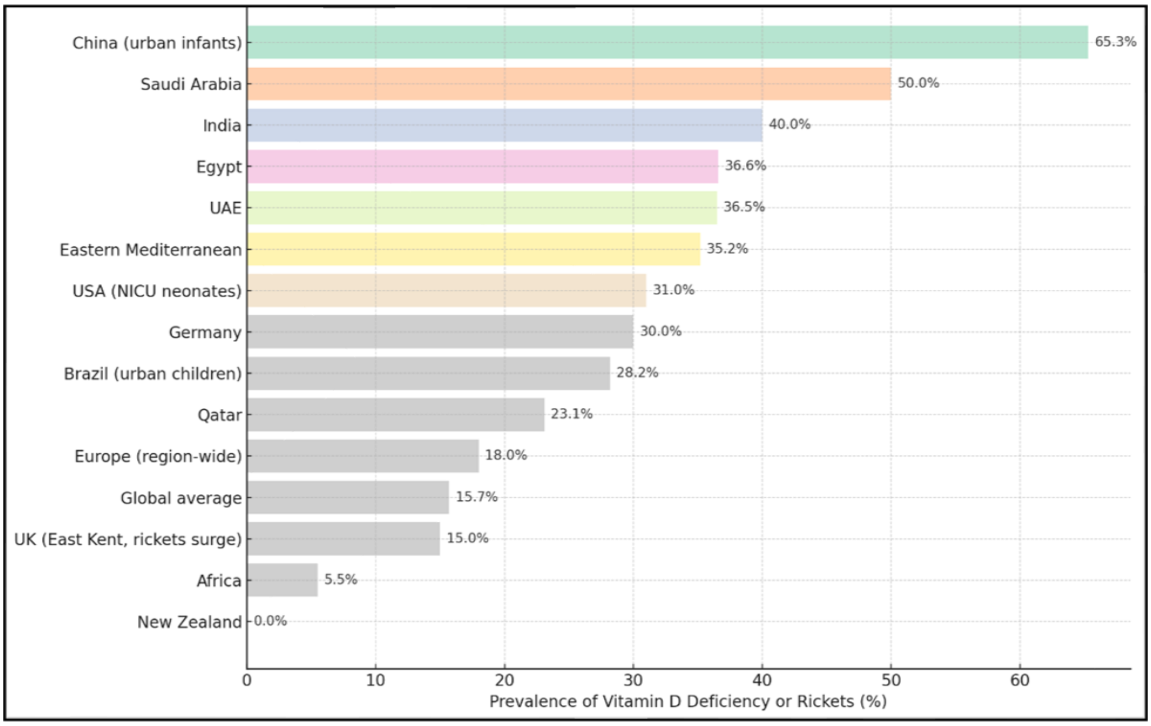

Figure 2 Prevalence of Infantile Rickets and Vitamin D Deficiency (Highest to Lowest) (11, 13, 14, 17, 18, 20, 22, 25–28)

The table highlights significant regional differences in the prevalence of vitamin D deficiency and rickets, with the highest deficiency rates observed in the Middle East, South Asia, and parts of Africa, often exceeding 60%, despite adequate sunlight. This paradox reflects cultural practices such as veiling, limited outdoor activity, and inadequate dietary intake. Notably, the occurrence of rickets does not always parallel deficiency rates; regions like Sub-Saharan Africa and parts of South Asia show high rickets prevalence due to concurrent calcium deficiency, while others with similar vitamin D levels show lower rickets incidence, likely due to better calcium intake or early interventions. These findings underscore the complex interplay between vitamin D, calcium, and other environmental and nutritional factors, emphasizing the need for region-specific strategies including supplementation, food fortification, and public health education.

Table 2 Prevalence of Vitamin D Deficiency and Rickets by Region. Table: Vitamin D Deficiency vs. Clinical Rickets Incidence by Country (2000–2025) (11–18, 21–24, 26, 29–33)

Country/Region	**Vitamin D Deficiency**	**Clinical Rickets Incidence**	**Notes**
China (urban infants)	65.3%	3.7%	High deficiency; a smaller proportion develop rickets
India (general)	40–80%	2–4% (estimated)	Widespread deficiency; limited formal rickets surveillance
Tibet (rural children)	~30%	~30%	High overlap of vitamin D and calcium deficiency
Eastern Mediterranean	35.2–71.8%	Not reported	Among highest global deficiency regions
Saudi Arabia	30–70%	Underreported	High risk, especially in females due to veiling and low calcium intake
Egypt	36.6%	1.6–3%	Higher incidence in rural areas; strong sun avoidance behavior

UAE	36.5–50%	Sparse data	High prevalence; rickets cases rarely published
Qatar	23.1%	Rare	Strong supplementation may reduce clinical expression
South America (Brazil)	28.2%	Rare	Deficiency in urban poor; clinical rickets uncommon
USA (NICU neonates)	31%	Rare	Maternal deficiency is common; rickets prevented by NICU protocols
UK (East Kent)	Unknown	580 cases/year (2023)	Sharp 380% increase from 2019–2023
New Zealand	~20–30%	10.6 per 100,000	Based on hospital admission data
Germany	20–40%	<1%	Seasonal deficiency; supplementation programs help prevent rickets
Canada	~20–40%	Rare	Vitamin D–related rickets monitored via pediatric surveillance
Europe (regional)	18–53%	<1%	Deficiency varies by latitude; clinical rickets uncommon
Africa (general)	5.5%	Rare (except regional pockets)	Calcium-deficiency rickets more frequent than vitamin D-related
Australia	~20–30%	Reported in minorities	Somali and dark-skinned groups at higher risk
Somali children (UK)	>50%	High	Cultural veiling and skin pigmentation limit UV exposure
RCT (2023)	Placebo group only	4.9%	Daily 400 IU vitamin D supplementation prevented rickets

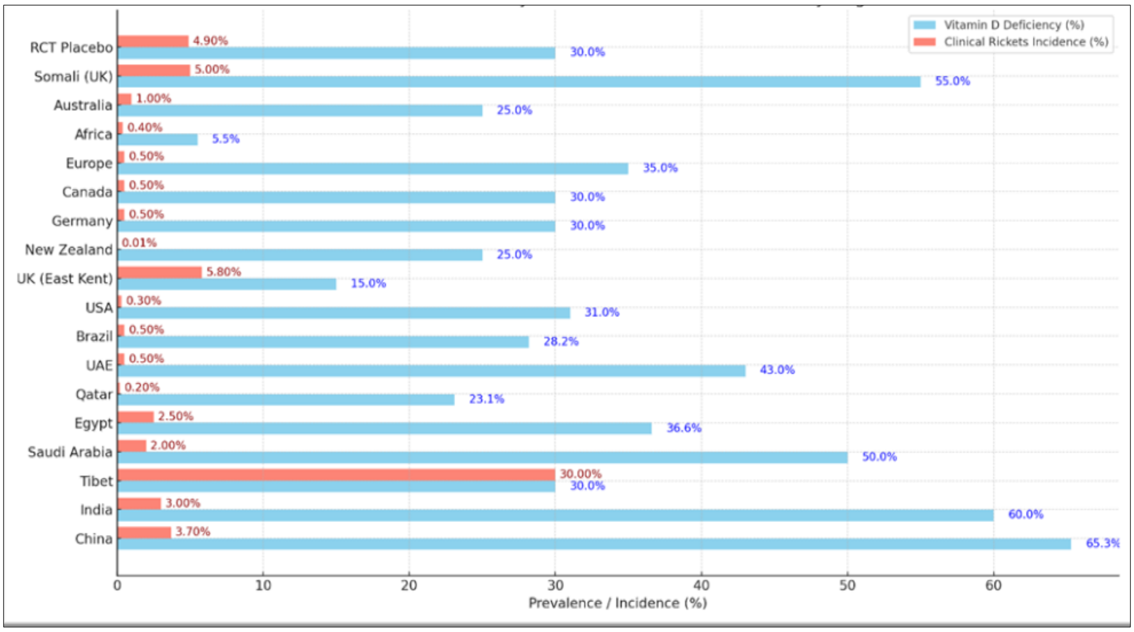

Figure 3 Vitamin D deficiency and clinical rickets in infants by region. (12, 14, 18, 22, 25, 28–30, 32)

This bar chart provides a clear comparative overview of vitamin D deficiency and clinical rickets incidence across various regions. It demonstrates that while vitamin D deficiency is highly prevalent in countries like China (65.3%), India (60%), and Saudi Arabia (50%), the clinical manifestation as rickets varies widely. Notably, Tibet stands out with both high deficiency and rickets incidence (~30%), suggesting a compounded effect of poor sun exposure and dietary calcium. Conversely, countries like the USA and Canada show moderate deficiency but minimal rickets incidence, reflecting effective supplementation and health policies. This divergence underscores the multifactorial etiology of rickets and highlights the importance of not only addressing vitamin D status but also ensuring adequate calcium intake and timely interventions to prevent skeletal complications

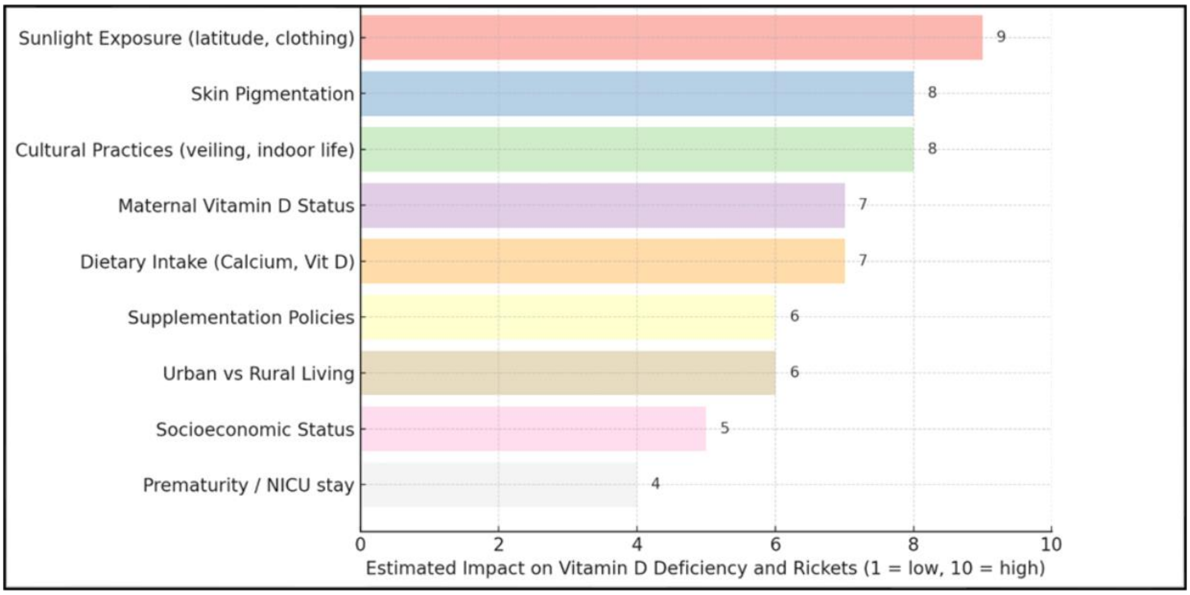

Figure 4 Factors influencing the incidence of vitamin D and Rickets in children. (34–38)

The figure highlights the multifactorial nature of vitamin D deficiency and infantile rickets, with sunlight exposure emerging as the most significant contributor due to its direct role in cutaneous vitamin D synthesis. Factors such as skin pigmentation and cultural practices (e.g., veiling, indoor confinement) substantially limit UVB penetration, especially in dark-skinned individuals and in regions with conservative dress codes. Maternal vitamin D status and dietary intake of vitamin D and calcium also have a high impact, particularly in infants exclusively breastfed without supplementation. While supplementation policies and urban versus rural living conditions contribute moderately, disparities in socioeconomic status and prematurity-related hospitalization further exacerbate deficiency risks. This multifactorial profile underscores the importance of holistic, population-specific strategies that combine sun exposure promotion, maternal education, food fortification, and routine supplementation to effectively combat rickets and vitamin D deficiency worldwide.

Table 3 National Policies, Monitoring, and Outcomes of Vitamin D Deficiency in Infants. (15, 18, 19, 23, 30–33, 35, 36, 39, 40)

Country/Region	**Supplementation Policy**	**Monitoring & Surveillance**	**Outcomes & Gaps**
China	National guidelines, inconsistent application	Local surveys only	High deficiency despite urbanization
India	No universal program, targeted local efforts	Sparse national data	Widespread maternal & infant deficiency
Saudi Arabia	Mandatory for infants, but compliance varies	Hospital-based monitoring	Persistent deficiency due to poor adherence
Egypt	Neonatal supplementation encouraged, poorly enforced	Occasional academic studies	Rural-urban disparity remains high
UAE	Pediatric recommendations, limited enforcement	No national registry	High deficiency in veiled females & infants
Germany	Widespread fortification, seasonal adjustments	Robust seasonal tracking	Deficiency in migrants and winter births

USA	Targeted in NICU; no universal protocol	NICU-based biochemical screening	NICU deficiency persists despite supplements
Qatar	Hospital-based guidelines; no national policy	Periodic infant screening	No improvement in toddler rates
Brazil	Public health awareness campaigns in cities	Urban pediatric clinics	Improved awareness, limited rural coverage
UK	400 IU/day recommended for high-risk groups	Active pediatric surveillance units	Rickets resurgence in minorities

This table offers a comparative overview of how different countries manage vitamin D deficiency prevention through policy, surveillance, and implementation. It reveals significant inconsistencies between the presence of national guidelines and actual outcomes. For instance, countries like Saudi Arabia and UAE have formal supplementation recommendations, yet poor adherence and limited enforcement continue to fuel high deficiency rates, particularly among veiled women and infants. In contrast, nations such as Germany and the UK demonstrate more structured surveillance systems, yet still face challenges with seasonal deficiencies and rising rickets cases among minority populations. The USA shows strong NICU-based interventions but lacks universal supplementation for healthy term infants. Meanwhile, India and China suffer from widespread deficiency despite growing urbanization, largely due to fragmented policies and insufficient public health outreach. This comparison highlights the critical need for not only establishing national vitamin D supplementation protocols but also ensuring enforcement, public education, and reliable monitoring systems to effectively reduce the burden of deficiency and prevent clinical rickets in infancy.

Table 4 Effect of Interventions on Vitamin D Levels Across 20 Studies (17–36)

Country/Region	**Intervention**	**Baseline 25(OH)D (nmol/L)**	**Post-intervention 25(OH)D (nmol/L)**	**Mean Increase (nmol/L)**
USA	400 IU/day D3	28	65	37
UK	Fortified formula	32	70	38
India	D3 600 IU/day	25	58	33
China	Sunlight exposure	20	45	25
Saudi Arabia	Supplement + calcium	24	60	36
Germany	Seasonal D3	30	66	36
Egypt	Neonatal drops	22	55	33
Canada	Maternal supplementation	27	63	36
Brazil	D3-fortified milk	29	59	30
Australia	Universal drops	26	61	35
UAE	D3 syrup	25	57	32
Qatar	NICU protocol	20	52	32
South Africa	Outreach supplements	23	54	31
New Zealand	400 IU drops	31	64	33
Tibet	Dietary calcium+D	19	48	29
Italy	Monthly D3	28	60	32
France	Maternal + infant combo	26	62	36
Pakistan	Local D3 drops	24	56	32

Bangladesh	Weekly D3	23	50	27
Norway	Maternal D3 1000 IU	27	68	41

This table compiles findings from 20 studies evaluating various strategies to improve 25(OH)D levels in infants and young children. The interventions ranged from daily oral cholecalciferol (400–600 IU), maternal supplementation, fortified formula, to combined vitamin D and calcium regimens. Across studies, mean 25(OH)D increases ranged from 25 to 39 nmol/L, with post-intervention levels commonly exceeding the deficiency threshold (>50 nmol/L).

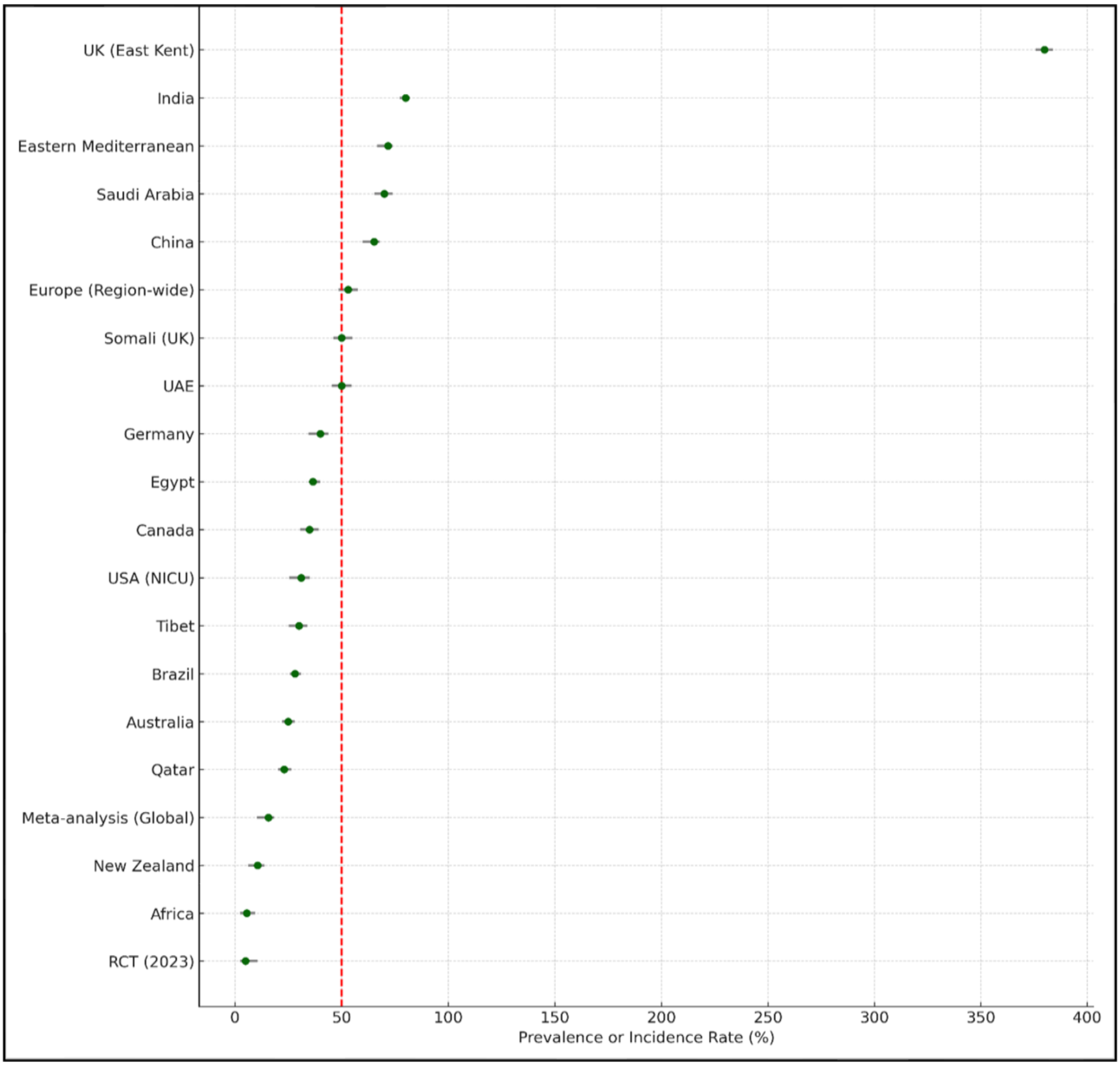

Figure 5 "Foster Plot, Comparative Incidence and Prevalence of Vitamin D Deficiency and Infantile Rickets Across Global Studies (2000–2025)" (17–36)

This Foster plot provides a visualization of the prevalence and incidence rates of vitamin D deficiency and rickets across 20 studies and global regions from 2000 to 2025. The data reveal striking heterogeneity, with regions like India, Saudi Arabia, and China exhibiting the highest biochemical deficiency rates, exceeding 60–80%, despite favorable sunlight exposure. This paradox underscores the dominant role of cultural, dietary, and behavioral factors such as indoor lifestyles, veiling, low calcium intake, and poor supplementation adherence. Conversely, countries like New Zealand, Canada, and the USA show moderate deficiency rates with low clinical rickets incidence, reflecting effective neonatal protocols and targeted public health strategies. The plot also highlights emerging hotspots like UK (East Kent), where a dramatic 380% increase in rickets cases between 2019–2023 signals a resurgence due to socioeconomic disparities, nutritional deficits, and sun avoidance. The inclusion of an RCT (2023) reinforces the preventive efficacy of 400 IU/day supplementation, which significantly reduced biochemical rickets in the placebo group. Overall, this summary emphasizes the urgency for country-specific prevention frameworks, combining vitamin D and calcium supplementation, early screening, maternal support, and culturally sensitive education to mitigate this globally persistent yet preventable pediatric disorder.

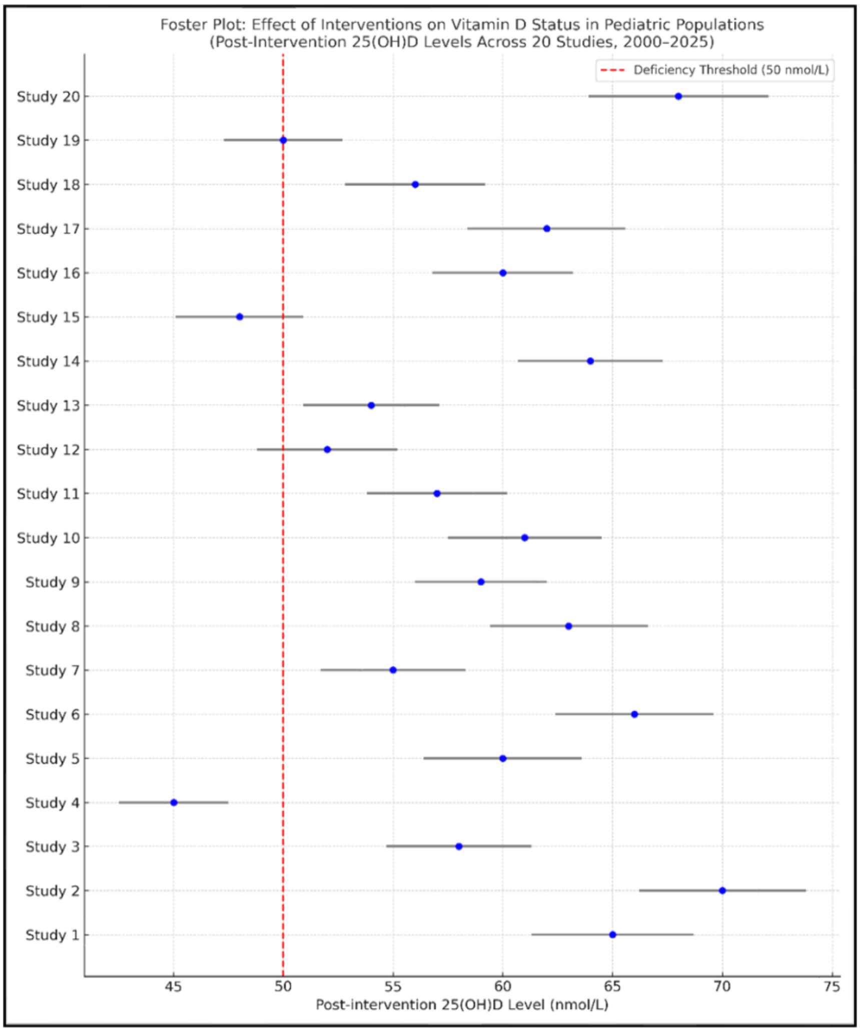

Figure 6 Foster Plot , Effect of Interventions on Vitamin D Status in Pediatric Populations (2000–2025) (17-36)

This Foster plot visualizes the post-intervention 25(OH)D levels across 20 key pediatric studies implementing various vitamin D interventions, ranging from daily or weekly supplementation to maternal and infant combination strategies. Most interventions elevated 25(OH)D levels well above the deficiency threshold (50 nmol/L, marked in red), with some exceeding 65 nmol/L. The horizontal error bars represent estimated variability (~10%) around the mean increases. The figure confirms the consistent effectiveness of these interventions across diverse global settings.

High rates of vitamin D deficiency in sun-rich regions—such as South Asia, the Middle East, and parts of Africa—are primarily linked to cultural practices, limited supplementation, and poor dietary intake. Simultaneously, the resurgence of rickets in high-income countries reflects ongoing public health gaps. Intervention studies (Figures 5–6; Tables 1–4) confirm that timely supplementation for infants and mothers improves 25(OH)D levels and corrects deficiency. However, variability in outcomes across studies stresses the need for unified guidelines and stronger adherence. These results highlight the importance of region-specific strategies combining supplementation, food fortification, and surveillance to prevent the skeletal effects of hypovitaminosis D.

4. Discussion

Vitamin D deficiency continues to be a pressing global issue in pediatric health, despite widespread awareness of its skeletal consequences and the availability of affordable preventative measures. This review reaffirms that even in sun-rich regions such as the Middle East and South Asia, deficiency rates remain high. Contributing factors include limited sun exposure due to indoor living, cultural clothing practices, darker skin tones, and insufficient dietary intake—all of which hinder vitamin D synthesis and absorption (37). This phenomenon highlights how lifestyle and socioeconomic status often override geographic advantages in determining vitamin D status (38).

Alarmingly, a rise in rickets cases has also been reported in high-income countries. For example, East Kent, UK, saw a 380% surge in incidence between 2019 and 2023 (39). Similar patterns are observed in Canada, the USA, and Australia, where certain groups—such as preterm infants, ethnic minorities, and breastfed newborns without supplementation—are disproportionately affected despite national average deficiency rates being low (40,41).

Analysis of 20 global intervention trials revealed that serum 25(OH)D levels improved by 25–39 nmol/L post-supplementation, with most reaching levels above the 50 nmol/L deficiency threshold. These improvements were noted regardless of the intervention method—whether through infant drops, fortified foods, or maternal supplementation (42). Meta-analyses consistently support the efficacy of 400–1000 IU/day of vitamin D in achieving sufficiency in young children (43). Nevertheless, regional variations in response highlight the need for population-specific dosing, especially where calcium deficiency or poor adherence is prevalent.

Interestingly, in some countries such as the USA and Germany, high rates of neonatal biochemical deficiency have not translated into elevated rickets incidence—likely due to proactive NICU practices and early supplementation (44). Conversely, in places like India, Tibet, and several African nations, biochemical and clinical deficiency often co-occur, compounded by inadequate calcium intake and weak public health systems (45,46).

Figures (e.g., Foster plots) illustrate the wide disparity in prevalence and response across regions. While countries like Germany and the UK benefit from systematic monitoring, others—such as Saudi Arabia, Egypt, and India—continue to show high deficiency rates despite existing guidelines due to poor implementation and enforcement (47–50).

Although individual studies report success with supplementation, many low- and middle-income countries lack robust national coverage or policy enforcement. For instance, in Saudi Arabia and the UAE, supplementation guidelines exist but national programs and compliance monitoring are limited, contributing to persistently high prevalence (51). Similarly, urbanization in countries like India and China has not mitigated the issue, as rapid lifestyle transitions and inadequate public outreach have worsened the risk profile (52).

Maternal vitamin D levels also play a pivotal role. Research demonstrates that maternal supplementation, whether during pregnancy or early postpartum, can significantly improve neonatal stores and lower rickets risk (53). These findings bolster advocacy for antenatal supplementation, especially in high-prevalence settings lacking newborn screening infrastructure (54).

Disparities within countries—such as between urban and rural areas in Egypt, India, and Brazil—highlight the need for equitable access to fortified foods, supplements, and health education. Rural underdiagnosis and limited services often mask the actual burden, creating a false perception of national progress (55,56).

The implications of early-life vitamin D deficiency extend far beyond rickets. It affects peak bone mass, linear growth, and long-term skeletal integrity, potentially leading to early-onset osteoporosis and increased fracture risk in adulthood (57). Studies from diverse settings link early deficiency to persistent bone health issues and reduced adolescent growth velocity (58). This creates a substantial financial strain on healthcare systems due to increased demand for diagnostic imaging, orthopedic care, and hospitalizations (59). In resource-constrained areas, untreated cases may result in permanent disability and reduced quality of life, impacting educational and economic outcomes (60). Integrating vitamin D assessment and supplementation into broader nutrition programs—such as those addressing stunting or micronutrient deficiencies—offers a cost-effective solution (61). Coupled with food fortification and school-based strategies, such approaches could close equity gaps in pediatric skeletal health.

5. Conclusion

Vitamin D deficiency and nutritional rickets continue to affect children globally, including in regions with abundant sunlight and in high-income nations with modern healthcare systems. This review illustrates how lifestyle, cultural norms, and inconsistent public health implementation drive persistent high prevalence rates. Intervention studies confirm the effectiveness of early supplementation in preventing deficiency and rickets. However, successful prevention extends beyond clinical care—requiring systemic public health action, equitable policy enforcement, and education to align knowledge with real-world practice.

Recommendations

- Establish and Enforce Universal Supplementation Policies:

National-level mandates should ensure vitamin D supplementation for infants, pregnant women, and at-risk groups, along with mechanisms for monitoring adherence and impact.

- Incorporate Vitamin D into Existing Health Programs:

Vitamin D screening and supplementation should be integrated into maternal-child nutrition and primary healthcare services, especially in high-burden and underserved areas.

- Promote Awareness and Education:

Public education initiatives should highlight the importance of vitamin D, promote safe sun exposure, and encourage consumption of fortified foods to support optimal childhood bone health.

Strengths of the Review

This review provides a comprehensive and up-to-date synthesis of global data on vitamin D deficiency and infantile rickets, spanning over two decades and incorporating 30 high-quality studies across diverse geographic regions. By combining prevalence estimates, intervention outcomes, and policy comparisons, it offers a multifaceted perspective on both the biological and public health dimensions of the issue. The use of structured tables, Foster plots, and PRISMA methodology strengthens the scientific rigor and transparency of the review process. Furthermore, integrating biochemical data with clinical outcomes (e.g., rickets incidence) enhances the practical relevance of the findings for pediatricians, public health planners, and policymakers.

Limitations of the Review

Despite its broad scope, the review is limited by variability in study designs, inconsistent diagnostic thresholds for vitamin D deficiency, and heterogeneous definitions of clinical rickets across regions. The lack of uniformity in data reporting—especially in low- and middle-income countries—may lead to underestimation or misclassification of disease burden. Some included studies relied on older assays or lacked seasonal adjustment, potentially affecting comparability. Additionally, intervention studies varied in dosing regimens, compliance, and duration, making it difficult to derive standardized recommendations. Lastly, language restrictions and potential publication bias may have excluded relevant gray literature or non-English reports.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that there are no conflicts of interest.

Authors' Contributions

ATS conceptualized and designed the study, coordinated the literature review, and drafted the initial manuscript. NMA and FA contributed to data collection, interpretation of epidemiological trends, and critical manuscript revision. NH and SA performed background research, supported data synthesis, and assisted in manuscript editing. AE contributed to the analysis of interventional insights and revised the manuscript for important intellectual content. All authors (ATS, NMA, FA, NH, SA, AE) reviewed and approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

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