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Review Article

Bone health in crisis: Addressing Vitamin D deficiency in orthopedic practice

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ABSTRACT

Vitamin D deficiency is increasingly recognized as a major contributor to musculoskeletal conditions, particularly in pediatric populations. This review focuses on the role of vitamin D in bone health, highlighting its deficiency as a key factor in the development of conditions such as rickets, osteomalacia, skeletal deformities, and an elevated risk of fractures. Vitamin D is essential for calcium and phosphate homeostasis, which are crucial for bone mineralization and growth. A deficiency disrupts these processes, leading to soft, weak bones and a range of orthopedic issues.

Children with vitamin D deficiency often present with musculoskeletal pain, delayed growth, bowing of the legs, and recurrent fractures, all of which can have long-term consequences if not addressed early. Diagnostic approaches, including serum vitamin D measurement, radiographic evaluation, and bone mineral density assessment, are critical for timely identification. Treatment typically involves vitamin D supplementation, dietary adjustments, and lifestyle changes, such as increased exposure to sunlight.

This review highlights the importance of early recognition and management of vitamin D deficiency within orthopedic practice to prevent severe musculoskeletal complications. By addressing this deficiency proactively, orthopedic practitioners can play a vital role in improving bone health and preventing lifelong orthopedic disabilities.

1. Introduction

Vitamin D plays a crucial role in calcium and phosphorus metabolism, which are essential for healthy bone formation and musculoskeletal development in children. With its deficiency, children are at risk for several musculoskeletal conditions due to reduced bone mineral density (BMD). Despite the abundant availability of sunlight, vitamin D deficiency remains highly prevalent among children worldwide, including regions with abundant sunshine. Sedentary lifestyles, inadequate outdoor activity, and poor dietary intake further exacerbate the issue. This review focuses on the orthopedic implications of vitamin D deficiency in children and explores how modern lifestyle factors contribute to this growing health concern.[1]

Vitamin D deficiency has been historically linked to various musculoskeletal conditions, with rickets being one of the earliest recognized disorders. In the 17th century, rickets was prevalent among children in industrialized cities with limited sunlight exposure.[2] The discovery of vitamin D in the early 20th century led to fortification of foods, significantly reducing rickets in many countries.

However, vitamin D deficiency remains a global public health issue, especially in children, due to modern lifestyles. Reduced outdoor activity, excessive screen time, urbanization, and the use of sunscreen have contributed to insufficient sun exposure. This has resulted in a resurgence of conditions such as rickets, osteomalacia, and an increased incidence of fractures, growth retardation, and muscle weakness in children.

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Prevalence is particularly high in regions with limited sunlight or where cultural practices limit skin exposure. Studies show that vitamin D deficiency affects 30-50% of children globally, making musculoskeletal complications a significant concern in pediatric health. The prevalence of vitamin D deficiency in children varies significantly across different countries due to factors such as geographic location, lifestyle, diet, and cultural practices (Table 1)

2. Literature Review

2.1. Vitamin D physiology and musculoskeletal health

Vitamin D, synthesized in the skin via exposure to ultraviolet B (UVB) rays, undergoes conversion to its active form, calcitriol, in the liver and kidneys. Calcitriol enhances intestinal absorption of calcium and phosphorus, critical for bone mineralization. In children, deficient levels of vitamin D can lead to impaired bone growth and structural integrity, causing a spectrum of orthopedic disorders.[3] (Figure 1)

3. Orthopedic Conditions Associated with Vitamin D Deficiency

Vitamin D deficiency in children has profound orthopedic implications, most notably seen in conditions like rickets, osteomalacia, increased fracture risk, and impaired skeletal development. Rickets is the classic manifestation of severe vitamin D deficiency, characterized by defective bone mineralization and growth plate abnormalities, leading to clinical presentations such as bowing of the legs (genu varum), delayed fontanelle closure, and skeletal deformities. Osteomalacia, prevalent in older children and adolescents, results in soft bones due to defective mineralization, manifesting as musculoskeletal pain, skeletal deformities, and heightened fracture risk. Vitamin D deficiency is also strongly associated with fractures, as it reduces bone mineral density (BMD), making children more susceptible to fractures, particularly in the forearm and lower extremities, even from low-energy impacts. Additionally, vitamin D is critical for optimal skeletal development and growth, especially during childhood's peak bone mass acquisition period. Inadequate vitamin D levels during this time can lead to stunted growth, increasing the long-term risk of osteoporosis and other musculoskeletal disorders. Understanding these conditions underscores the vital role of vitamin D in orthopedic health and emphasizes the need for early prevention and intervention.[4,5] (Table 2)

The importance of this literature on the role of vitamin D deficiency in musculoskeletal conditions is multi-faceted**:** (Table 3)[6–24]

1. **Enhanced Understanding of Vitamin D's Role**: This body of research establishes the critical role of vitamin D in bone health and musculoskeletal development, highlighting its significance in preventing diseases such as rickets, osteomalacia, and fractures in children. It emphasizes how vitamin D is not only vital for bone mineralization but also for overall musculoskeletal function, which includes muscle strength and mobility.
2. **Public Health Implications**: The literature underscores the global prevalence of vitamin D deficiency, particularly in children. With studies from countries such as India, the UK, Nigeria, and the USA, it demonstrates that vitamin D deficiency is a worldwide concern with widespread health implications, particularly in regions with limited sun exposure or poor dietary habits. Understanding this can help shape public health policies focusing on supplementation, fortified foods, and outdoor activities.
3. **Clinical Guidelines**: This research informs orthopedic and pediatric practitioners about the diagnostic methods, treatment options, and preventive strategies for managing vitamin D deficiency-related musculoskeletal conditions. It provides a foundation for evidence-based clinical guidelines for early diagnosis and intervention, which can prevent long-term skeletal deformities and improve patient outcomes.
4. **Impact on Lifestyle**: The literature links modern lifestyle factors, such as reduced outdoor activity and poor nutrition, to the increasing rates of vitamin D deficiency in children. This has crucial implications for lifestyle modification and public education, encouraging balanced exposure to sunlight and the incorporation of vitamin D-rich foods in daily diets.
5. **Prevention and Management**: By consolidating studies on the effectiveness of vitamin D supplementation in reversing conditions like rickets and improving bone density, this literature highlights the preventive and therapeutic potential of maintaining optimal vitamin D levels. It emphasizes the need for preventive measures such as regular screening, dietary fortification, and public health interventions, particularly in high-risk populations.

In conclusion, this literature is critical for understanding the significant role of vitamin D in musculoskeletal health, its global prevalence, and the actionable measures required to address this widespread deficiency.

4. Lifestyle Factors Contributing to Vitamin D Deficiency

1. **Reduced Outdoor Activity:** Modern lifestyles, dominated by screen time and indoor activities, have resulted in a significant reduction in outdoor exposure to sunlight. Studies have shown that children who spend more time indoors are at higher risk for vitamin D deficiency due to insufficient UVB exposure

necessary for vitamin D synthesis.

2. **Dietary Habits:** Many children have diets deficient in vitamin D-rich foods such as fatty fish, fortified dairy products, and eggs. Additionally, the increasing consumption of processed foods, which lack essential nutrients, contributes to suboptimal vitamin D intake.
3. **Clothing and Cultural Practices:** In some regions, cultural practices involving covering the skin for religious or traditional reasons further limit sunlight exposure, increasing the risk of vitamin D deficiency.
4. **Urbanization and Air Pollution:** Urban living often leads to decreased exposure to direct sunlight due to tall buildings, air pollution, and limited access to outdoor recreational areas, all of which reduce the UVB rays necessary for vitamin D synthesis.

5. Discussion

The prevalence of vitamin D deficiency in children is a significant public health issue that has direct orthopedic consequences. The role of vitamin D in skeletal development is well-established, and its deficiency is linked to numerous musculoskeletal disorders, including rickets, osteomalacia, and increased fracture risk.

The current lifestyle trends of children are directly contributing to this deficiency. With increased screen time, sedentary habits, and limited outdoor activities, children are not getting adequate exposure to sunlight, which is the most critical source of vitamin D. Furthermore, dietary inadequacies, including low intake of vitamin D-rich foods, compound this problem.

From an orthopedic perspective, the implications of untreated vitamin D deficiency are profound. In addition to classical skeletal deformities such as bowlegs and knock-knees, children with low vitamin D levels are at a higher risk of developing osteoporosis and suffering from fractures. These musculoskeletal complications can lead to long-term disability, increased healthcare costs, and reduced quality of life.

Vitamin D deficiency in children has a significant and multifaceted impact on musculoskeletal health, leading to a variety of orthopedic conditions with lasting consequences. The most well-known manifestation of severe vitamin D deficiency is rickets, a condition characterized by defective bone mineralization and impaired growth plate function. Children with rickets often present with classic orthopedic deformities such as bowed legs (genu varum), knock knees (genu valgum), delayed closure of fontanelles, and deformities of the chest (such as a rachitic rosary, where the ribs and costal cartilage junctions become prominent). These deformities arise because, without adequate vitamin D, calcium and phosphate cannot be properly absorbed, leading to weak and soft bones, particularly at the growth plates, where rapid bone development occurs.

Table 1: Summary of the prevalence of vitamin D deficiency in children:

Country	Prevalence of Vitamin D Deficiency in Children	Key Factors
India	50-90%	Urbanization, limited sun exposure, cultural clothing practices
United States	9-18%	Sedentary lifestyle, low outdoor activity, dietary habits
United Kingdom	20-50%	Limited sunlight, high latitude, darker skin populations
China	45-65%	Air pollution, limited sun exposure in cities, dietary factors
Saudi Arabia	80-90%	Cultural clothing (covering), limited outdoor exposure
Canada	35-50%	High latitude, seasonal variation in sunlight
Australia	30-60%	Sunscreen use, reduced sun exposure
Middle East (General)	50-90%	Cultural practices, clothing, and dietary habits
Africa (North)	60-80%	Limited sun exposure, urban living, poor nutrition
Brazil	30-40%	Urbanization, inadequate sunlight exposure
South Africa	10-25%	Varies by region, access to sunlight

Table 2: Summarizes the musculoskeletal conditions associated with vitamin D deficiency, focusing on diagnostic approaches, clinical symptoms, treatment options, and preventive measures.

Condition	Clinical Symptoms & Signs	Investigations	Treatment	Prevention Measures
Rickets	- Bowlegs, knock knees, skeletal deformities	- Serum 25-hydroxyvitamin D (<20 ng/mL)	- Vitamin D supplementation (50,000 IU weekly for 6-8 weeks)	- Sunlight exposure (15-30 min/day)
	- Delayed growth, delayed tooth eruption	- Serum calcium (low), phosphorus (low)	- Calcium supplementation (500-1,000 mg/day)	- Vitamin D-rich foods (fish, eggs, fortified milk)
	- Muscle weakness, bone pain, widened wrists	- Alkaline phosphatase (ALP) (elevated)	- Surgical correction for severe skeletal deformities	- Vitamin D supplementation (400-800 IU/day)
	- Frontal bossing, rachitic rosary	- X-rays: cupping, fraying, metaphyseal widening		
Osteomalacia	- Diffuse bone pain, proximal muscle weakness	- Serum 25-hydroxyvitamin D (<20 ng/mL)	- High-dose vitamin D (50,000 IU weekly or 2,000-5,000 IU/day)	- Adequate dietary vitamin D and calcium intake
	- Difficulty walking, waddling gait	- Serum calcium and phosphorus (low)	- Calcium supplementation (1,000-1,500 mg/day)	- Encourage regular outdoor physical activities
	- Frequent fractures, delayed bone healing	- Bone biopsy (if necessary)	- Corrective surgery if deformities or fractures occur	
	- Looser's zones, pseudofractures on X-ray	- X-rays, DEXA scan for bone density		
Fractures	- Pain, swelling at the fracture site	- Serum 25-hydroxyvitamin D	- Conservative treatment (casting, bracing)	- Regular vitamin D supplementation
	- History of recurrent low-impact fractures	- X-rays: assess fracture pattern	- Surgical fixation for complex fractures	- Screening for vitamin D deficiency in high-risk children
	- Delayed bone healing	- Bone mineral density (DEXA scan)	- Vitamin D and calcium supplementation	- Regular physical activity
Growth Retardation	- Short stature, delayed growth milestones	- Serum 25-hydroxyvitamin D	- Vitamin D (400-800 IU/day) and calcium supplementation	- Ensure timely vitamin D supplementation in at-risk children
	- Widening of growth plates, delayed bone maturation	- Bone age assessment (wrist/hand X-ray)	- Monitor skeletal growth and development	- Pediatric screening in cases of delayed growth
Hypocalcemic Seizures	- Muscle spasms (tetany), seizures, cramps	- Serum calcium (low), phosphorus (low), 25-hydroxyvitamin D	- Acute: IV calcium gluconate, Oral calcium & vit D	- Daily vitamin D supplementation
	- Chvostek's sign, Trousseau's sign	- Serum magnesium (to rule out magnesium deficiency)	- Seizure management with anti-epileptics as needed	- Sunlight exposure and vitamin D-rich diet

Continued on next page

Table 2 continued

	- Neuromuscular irritability, irritability in infants	- Electrolyte panel		
Skeletal Deformities	- Bowed legs, pigeon chest, scoliosis	- Serum 25-hydroxyvitamin D	- Vitamin D supplementation (as per severity)	- Early detection and preventive supplementation
	- Prominent costochondral junction (rachitic rosary)	- X-rays of long bones (cortex thinning, deformities)	- Orthopedic surgical intervention in severe cases	- Balanced diet with sufficient calcium and vitamin D
Muscle Weakness & Fatigue	- Proximal muscle weakness, delayed motor milestones	- Serum 25-hydroxyvitamin D	- Vitamin D (1,000-2,000 IU/day)	- Ensure outdoor physical activities
	- Difficulty standing or walking, frequent falls	- Serum calcium, phosphorus, ALP	- Calcium supplementation	- Diet rich in vitamin D and calcium
Scoliosis	- Abnormal curvature of the spine	- X-ray: Cobb angle measurement	- Bracing in mild-to-moderate cases	- Prevent vitamin D deficiency in early childhood
	- Asymmetry in shoulder height, ribcage deformities	- Serum 25-hydroxyvitamin D	- Surgery in severe cases (spinal fusion, rod placement)	- Regular monitoring for vitamin D levels in scoliosis patients
Juvenile Osteoporosis	- Bone pain, increased fracture risk, delayed walking	- DEXA scan for bone mineral density	- Vitamin D (2,000-5,000 IU/day)	- Vitamin D and calcium-rich diet
	- Decreased height, limb deformities	- Serum 25-hydroxyvitamin D	- Calcium supplementation	- Ensure adequate sunlight exposure
	- Kyphosis, difficulty bearing weight	- Serum calcium and phosphorus	- Bisphosphonates for severe osteoporosis (rare in children)	- Regular screening for bone health in high-risk children
Osgood-Schlatter Disease	- Painful swelling below the knee (tibial tuberosity)	- Physical exam	- Pain management (NSAIDs, rest, activity modification)	- Adequate vitamin D and calcium intake to support bone growth
	- Tenderness over the tibial tubercle	- X-ray may show fragmentation of tibial tubercle	- Physical therapy (strengthening exercises)	- Prevent vitamin D deficiency during periods of rapid growth
Legg-Calvé-Perthes Disease	- Hip pain, limping, limited range of motion	- X-ray or MRI of the hip	- Rest and activity limitation	- Adequate vitamin D levels during skeletal development
	- Muscle atrophy in thigh, shortening of affected leg	- Serum 25-hydroxyvitamin D	- Physical therapy to maintain range of motion - Surgery (osteotomy, joint replacement in severe cases)	- Ensure balanced diet and physical activity

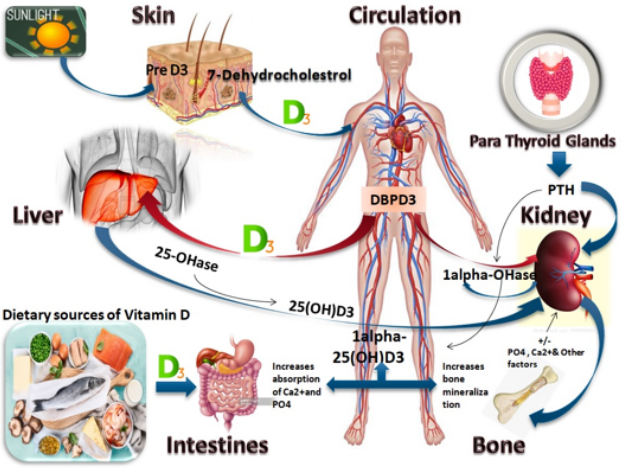

Figure 1: Showing the Vit D metabolism

In older children and adolescents, osteomalacia becomes a more common presentation of vitamin D deficiency. Unlike rickets, which primarily affects the growth plates, osteomalacia results in defective bone mineralization in mature bones, leading to soft, weakened bones throughout the body. This condition is often accompanied by diffuse musculoskeletal pain, skeletal deformities, and a higher risk of stress fractures, particularly in weight-bearing areas such as the hips and lower extremities. Adolescents with osteomalacia may also exhibit muscle weakness, fatigue, and difficulties with ambulation due to the structural compromise of their bones.

A crucial orthopedic consequence of vitamin D deficiency is its role in increasing susceptibility to fractures. Children with inadequate vitamin D levels are more prone to fractures, even from relatively minor trauma. This is due to the decrease in bone mineral density (BMD) caused by the impaired absorption of calcium and phosphate. Studies have shown that children with low vitamin D levels are at a significantly higher risk of both low-energy fractures (such as falls from standing height) and high-energy fractures (such as sports injuries). The forearm, wrist, and lower extremities are common sites of fractures in vitamin D-deficient children, and these injuries can result in long-term complications if not managed properly.

Beyond immediate orthopedic concerns, vitamin D deficiency can have profound effects on *skeletal development and growth* during critical periods of childhood. Vitamin D is essential for the proper formation of peak bone mass, a crucial determinant of lifelong bone health. Insufficient vitamin D during these formative years can lead to stunted growth and improper bone formation, increasing the risk of osteoporosis and other musculoskeletal disorders later in life. Children with low vitamin D levels may not reach their full genetic potential for height and may suffer from reduced bone strength, predisposing them to fractures and other orthopedic issues as they age.

Understanding the orthopedic impact of vitamin D deficiency is crucial for early diagnosis and treatment. Clinically, orthopedic surgeons should be vigilant for signs of bone pain, skeletal deformities, delayed milestones (such as walking or standing), and frequent fractures in children, all of which could indicate underlying vitamin D deficiency. Diagnostic tools such as serum vitamin D levels, X-rays showing characteristic bone changes (e.g., cupping and fraying of the metaphysis in rickets), and bone density scans can aid in the diagnosis. Treatment involves addressing the deficiency through vitamin D supplementation, dietary improvements, and lifestyle modifications, such as increased exposure to sunlight. In severe cases of deformity, corrective surgery may be necessary, especially if the bone abnormalities affect function or cause significant pain. Prevention remains key, with strategies focusing on public health interventions to promote adequate vitamin D intake, early childhood screenings, and education on the importance of outdoor physical activity and nutrition. Orthopedic interventions, such as surgical correction of deformities, may be required in severe cases, but the primary focus should be on prevention.

The literature is critical for understanding the significant role of vitamin D in musculoskeletal health because it sheds light on how deficiencies of this essential nutrient can lead to conditions such as rickets, osteomalacia, and delayed bone growth in children. By highlighting the biochemical pathways through which vitamin D influences calcium absorption and bone mineralization, these studies underscore its importance in maintaining strong and healthy bones.

The global prevalence of vitamin D deficiency, as documented in multiple studies across countries like India, Nigeria, the USA, and the UK, emphasizes that this is not a localized issue but a widespread public health concern. Particularly in regions with limited sun exposure or poor access to vitamin D-rich diets, the risk of deficiency-related musculoskeletal problems is elevated. This global perspective helps inform both local and international health strategies.

Finally, these studies provides actionable measures for addressing vitamin D deficiency, such as advocating for regular screening, vitamin D supplementation, the fortification of foods, and promoting lifestyle changes like increased outdoor activities. These evidence-based recommendations can guide healthcare providers and policymakers in developing strategies to reduce the burden of vitamin D deficiency and its related musculoskeletal conditions in children.

Table 3: Summarizing studies that highlight the role of vitamin D deficiency in leading to musculoskeletal conditions in children

Study	Country	Year	Sample Size	Musculoskeletal Conditions	Key Findings
Holick et al.	USA	2007	1,500	Osteomalacia, fractures	Vitamin D deficiency linked to impaired bone mineralization
Misra et al.	India	2008	432	Rickets	Severe vitamin D deficiency found in urban children with rickets
Ward et al.	UK	2011	1,024	Rickets, delayed motor development	High prevalence of rickets in children with low vitamin D levels
Lee et al.	South Korea	2014	562	Osteopenia, scoliosis	Vitamin D deficiency associated with decreased bone density
Munns et al.	Australia	2012	231	Rickets	Vitamin D supplementation effectively reversed rickets in children
El-Hajj Fuleihan et al.	Lebanon	2006	340	Bone deformities, muscle weakness	High prevalence of rickets due to low sun exposure
Dawodu et al.	UAE	2005	650	Fractures, growth retardation	Vitamin D deficiency linked to increased fracture risk
Thacher et al.	Nigeria	2009	302	Rickets, bow legs	Dietary factors and limited sun exposure linked to high rickets rates
Marwaha et al.	India	2010	1,000	Rickets, muscle pain	Significant association between vitamin D deficiency and musculoskeletal pain
Winzenberg et al.	Australia	2011	422	Osteopenia, reduced bone mineral density	Vitamin D deficiency strongly correlated with reduced bone mass
Shah & Finberg	USA	2007	150	Fractures, delayed skeletal development	Vitamin D supplementation reduced fracture risk in at-risk children
Högler et al.	UK	2015	780	Rickets, skeletal deformities	Vitamin D deficiency seen as major contributor to pediatric bone deformities
Renzaho et al.	Australia	2014	510	Rickets, osteomalacia	Vitamin D deficiency linked to higher rates of musculoskeletal issues in immigrant populations
Chen et al.	China	2012	500	Growth retardation, fractures	Strong correlation between low vitamin D levels and growth disorders in children
Mithal et al.	India	2011	850	Bow legs, osteomalacia	Prevalence of vitamin D deficiency high in children with leg deformities
Ozkan et al.	Turkey	2009	312	Osteopenia, fractures	Low vitamin D levels increase fracture risk and cause osteopenia
Isaia et al.	Italy	2003	220	Osteomalacia	Vitamin D deficiency directly related to osteomalacia cases in children
Gonzalez-Gross et al.	Spain	2012	700	Muscle weakness, scoliosis	High rates of musculoskeletal conditions linked to vitamin D deficiency in adolescents
Çayir et al.	Turkey	2014	480	Rickets, scoliosis	Vitamin D supplementation prevented progression of scoliosis in deficient children
Callaghan et al.	Ireland	2008	180	Bone pain, fractures	Correction of vitamin D levels improved bone pain and reduced fracture incidence

6. Conclusion

Vitamin D deficiency in children is a growing concern, particularly in the context of modern lifestyles that limit sunlight exposure and promote unhealthy dietary patterns. The orthopedic consequences of this deficiency are significant, leading to conditions such as rickets, osteomalacia, and increased fracture risk. Addressing this issue requires a multifaceted approach involving increased public awareness, improved dietary habits, and encouraging outdoor activities. Orthopedic specialists should remain vigilant in recognizing the early signs of vitamin D deficiency and its musculoskeletal complications to prevent long-term disability in children.

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None.

8. Conflict of Interest

None.

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