DOI: 1021088/ijpen.2454.9126.12226.3

International Journal of Pediatric Nursing
Volume 12 Number 2, May – August 2026

REVIEW ARTICLE

Pediatric Bone Disorders: Interpretation Challenges of Vitamin D and Calcium

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HOW TO CITE THIS ARTICLE:

Madhumitha, Rajathisakthivel, D.K. Sriram. Pediatric Bone Disorders: Interpretation Challenges of Vitamin D and Calcium. Int J Pediatr Nurs. 2026; 12(2): 91–98.

ABSTRACT

Vitamin D and calcium metabolism are central to skeletal growth, mineralisation, and metabolic bone homeostasis in childhood, making laboratory assessment of these nutrients critical in pediatric bone disorders such as nutritional rickets, osteomalacia, metabolic bone disease of prematurity, chronic kidney disease-related mineral bone disorder, and selected inherited or malabsorptive conditions. Interpretation of laboratory markers in children is more difficult than in adults because normal values vary with age, growth velocity, pubertal stage, dietary intake, sun exposure, and underlying disease, while available diagnostic thresholds are not uniformly standardized across pediatric populations. Serum 25-hydroxyvitamin D is the preferred marker of vitamin D status. Still, its clinical meaning depends on simultaneous interpretation of calcium, phosphate, alkaline phosphatase, parathyroid hormone, renal function, and radiologic findings, particularly when bone disease is suspected. Additional complexity arises from assay variability, age-specific differences in reference intervals, and the overlap between calciopenic and phosphopenic disorders. This review summarizes the physiology of vitamin D-calcium-phosphate regulation, outlines key biochemical patterns in common pediatric bone disorders, analyzes major laboratory interpretation pitfalls, and summarizes practical strategies for more accurate diagnosis and monitoring in children.

KEYWORDS:

• Peadiatric • Bone Disorders • Calcium • Vitamin D • Serum 25-Hydroxyvitamin D • Osteomalacia • Calciopenic Disorders • Diagnostic Thresholds

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➢ **Received:** 14-07-2026 ➢ **Accepted:** 07-08-2026

INTRODUCTION

Pediatric skeletal health depends on the coordinated regulation of vitamin D, calcium, phosphate, parathyroid hormone, intestinal absorption, renal handling, and skeletal growth. Disruption at any point in this network can impair mineralisation and present with rickets, fractures, bone pain, growth delay, deformity, or incidental biochemical abnormalities. Laboratory interpretation is particularly challenging because children may show active bone disease despite only modest changes in serum 25-hydroxyvitamin D or normal total calcium concentrations maintained by compensatory secondary hyperparathyroidism. In addition, nutritional, renal, and inherited disorders may produce overlapping biochemical profiles, making individual test interpretation unreliable. For this reason, pediatric metabolic bone disease is best evaluated through integrated biochemical pattern recognition supported by clinical and radiologic correlation.[1,2]

Deficiency of vitamin D and calcium contributes to pediatric bone disorders, including nutritional rickets, osteomalacia, and impaired bone development, which remain important global health concerns. Vitamin D deficiency is highly prevalent among children worldwide, with reported rates ranging from 20% to over 80%, depending on geographical location, nutritional status, sunlight exposure, and socioeconomic factors. Nutritional rickets is most common in infancy and early childhood, especially in developing regions such as South Asia, where vitamin D deficiency affects a large proportion of children. Recent multi-center clinical data endorsed by the Indian Academy of Pediatrics (IAP) and Indian Council of Medical Research (ICMR) indicates that vitamin D deficiency remains a silent public health epidemic in India, affecting 50% to 90% of the pediatric population which is influenced by limited sun exposure, inadequate calcium intake, and lifestyle factors. Despite being preventable through supplementation and nutritional interventions, vitamin D and calcium-related bone disorders continue to pose a significant burden, underscoring the need for early diagnosis and preventive strategies.[3,4,5]

PHYSIOLOGY OF VITAMIN D AND CALCIUM METABOLISM

1. Vitamin D metabolism

Vitamin D is obtained through skin synthesis and dietary intake, then converted in the liver to 25-hydroxyvitamin D, the major circulating storage form used to assess vitamin D status, and subsequently converted in the kidney to 1,25-dihydroxyvitamin D, the active hormone that supports calcium absorption and mineral metabolism. Serum 25-hydroxyvitamin D is preferred for laboratory assessment because it has a longer half-life and better reflects body stores than 1,25-dihydroxyvitamin D, which may remain normal or rise in deficiency states due to parathyroid hormone stimulation.[6]

2. Calcium-phosphate - PTH axis

When vitamin D is low, intestinal absorption of calcium and phosphate falls, triggering parathyroid hormone secretion to preserve serum calcium. This compensatory response increases renal calcium reabsorption and phosphate wasting, helping to maintain calcium but worsening phosphate depletion and reducing bone mineralization over time. The result is that serum calcium may appear normal even when the patient is clinically significant with rickets or osteomalacia.[7]

3. Paediatric Considerations

Children differ from adults because mineral requirements change rapidly across infancy, childhood, and puberty, and because skeletal growth itself alters biochemical reference intervals. Values for phosphate and alkaline phosphatase are particularly age-dependent, which means adult reference cutoffs are often inappropriate in pediatric practice.

MAJOR PEDIATRIC BONE DISORDERS LINKED TO VITAMIN D AND CALCIUM METABOLISM

Pediatric metabolic bone disorders comprise a diverse group of conditions affecting skeletal growth, mineralization, density, and structural integrity during childhood and adolescence. They are broadly classified into major and minor disorders based on severity, frequency, and clinical impact. Major disorders include nutritional rickets, calcium-deficient rickets, vitamin D–dependent rickets, osteogenesis imperfecta, osteoporosis, renal osteodystrophy,

and hypophosphatemic rickets, because they commonly cause deformities, fractures, growth failure, or significant metabolic complications. Minor disorders include milder or transient conditions such as metabolic bone disease of prematurity, physiologic neonatal changes in calcium/phosphate balance, mild hypovitaminosis D without skeletal signs, and transient bone pain syndromes, which are usually less severe and may resolve with monitoring or simple supplementation.[8]

1. Nutritional Rickets and Osteomalacia

Nutritional vitamin D deficiency/ and or inadequate calcium intake remain the major causes of rickets in children, producing defective mineralisation at the growth plate and soft, poorly mineralised bone. Common laboratory findings include low 25-hydroxyvitamin D, elevated alkaline phosphatase, elevated parathyroid hormone, low or normal calcium, and low phosphate, though the exact pattern varies with timing and severity.[9]

2. Metabolic Bone Disease of Prematurity

Preterm infants are at increased risk because of reduced transplacental mineral transfer, low stores at birth, rapid postnatal growth, and nutritional challenges. In this setting, interpretation is complicated by gestational age, feeding strategy, and the fact that vitamin D status alone does not capture the full calcium-phosphate deficit underlying poor mineralization.[10]

3. Chronic Kidney Disease-Related Bone and Mineral Disorder

Children with chronic kidney disease may develop vitamin D deficiency, reduced activation of vitamin D, secondary hyperparathyroidism, and abnormal calcium-phosphate balance, all of which contribute to renal osteodystrophy and growth impairment. The biochemical profile can overlap with nutritional deficiency, but renal dysfunction and persistent PTH abnormalities alter both diagnosis and treatment response.[11]

4. Calciopenic Disorders & Phosphopenic Disorders

Calciopenic rickets is usually caused by nutritional vitamin D deficiency, low calcium intake, or rare genetic disorders affecting vitamin D metabolism or action. Phosphopenic rickets, by contrast, is driven primarily by renal phosphate wasting, as in X-linked hypophosphatemia, and typically presents with low phosphate despite normal calcium and often nondeficient vitamin D status. Distinguishing these categories is essential because their treatment strategies differ substantially.[12]

Table 1 summarises the expected biochemical profiles across the major pediatric bone disorders, highlighting how overlapping patterns can create diagnostic ambiguity. On analyzing the biochemical profiles, it is analyzed that serum 25-hydroxyvitamin D remains the primary indicator of vitamin D stores, but it should not be interpreted individually. Total calcium may remain normal during early deficiency because secondary hyperparathyroidism preserves circulating calcium. Hypophosphatemia and elevated alkaline phosphatase often provide stronger evidence of active disordered mineralisation, while parathyroid hormone helps identify compensatory endocrine activation. In children with suspected bone disease, magnesium, creatinine, liver function tests, urinary calcium, and radiographic findings may be required to clarify aetiology.

Table 1: Biochemical Profiles in Major Pediatric Bone Disorders[13]

Condition	25(OH)D	1,25$(OH)_2$ D	PTH	Calcium	Phosphate	ALP
Nutritional Vitamin D Deficiency	↓↓	Normal/↓	↑	Low/Normal	↓	↑↑
VDDR Type 1A	Normal/↑	↓↓	↑	↓	↓	↑↑
VDDR Type 2A	Normal/↑	↑↑	↑	↓	↓	↑↑
X-Linked Hypophosphatemia	Normal	Low/Normal	Normal	Normal	↓↓	↑
Primary Hyperparathyroidism	Low/Normal	↑	↑↑	↑	↓	↑
Hypoparathyroidism	Variable	↓	↓/Absent	↓	↑	Normal
Renal Osteodystrophy	Variable	↓	↑↑	↓/Normal	↑	↑
Hypophosphatasemia	Normal	Normal	Normal	Normal/↑	Normal/↑	↓↓

↑ = elevated, ↓ = reduced, ↓↓ = markedly reduced, ↑↑ = markedly elevated. ALP = alkaline phosphatase; PTH = parathyroid hormone; VDDR = vitamin D-dependent rickets.

DEFINING DEFICIENCY: THRESHOLDS AND AGE-SPECIFIC CONSIDERATIONS

Pediatric vitamin D deficiency requires balancing conflicting guideline philosophies with age-dependent metabolic and skeletal demands. In the latest IAP guidance, serum 25-hydroxyvitamin D is classified as deficient at <12 ng/mL, insufficient at 12–20 ng/mL, and sufficient at >20 ng/mL, while vitamin D toxicity is considered at >100 ng/mL with hypercalcemia and/or hypercalciuria. Calcium deficiency should be judged alongside age-specific serum calcium and urine calcium: creatinine limits, since normal total calcium may still mask disease. For treatment of nutritional rickets, the guideline recommends vitamin D plus calcium, with calcium intake adjusted by age and clinical severity. Thus, interpretation should combine biochemical cutoffs, growth stage, and clinical findings rather than relying on a single value elaborated in table 2.[3]

Tailoring these thresholds across age groups is critical: preterm neonates require higher clinical vigilance and supplementation due to missed third-trimester maternal transfers and the risk of metabolic bone disease; infants and toddlers rely on PTH as a vital functional co-marker to evaluate tissue-level adequacy when 25(OH)D levels are borderline; and adolescents face rapid skeletal turnover driven by pubertal shifts in 1,25,(OH)2D metabolism, elevating their risk for masked under-diagnosis during peak bone mass accumulation. Finally, to mitigate the risk of vitamin D toxicity, which is biochemically diagnosed by the triad of elevated 25(OH)D, hypercalcaemia, and suppressed PTH, guidelines enforce age-stratified tolerable upper intake levels ranging from 1,000 IU/day in neonates up to 4,000 IU/day in older children and adolescents.[14]

Table 2: Age-Specific Reference Intervals for Pediatric Bone Biomarkers[15]

Biomarker	Neonates (0–6 months)	Infants (7–12 months)	Toddlers (1–3 years)	Children (4–8 years)	Key Notes
25(OH)D	No age variation - ≥50 nmol/L recommended for all ages				- Deficiency: <20 ng/mL (50 nmol/L) - Insufficiency: 20–29 ng/mL (50–75 nmol/L) - Sufficiency: ≥30 ng/mL (≥75 nmol/L)
$1,25(OH)_2D$ (pg/mL)	20–80 highly variable	18–72	15–60	14–55	- Higher in children due to PTH stimulation - Can be paradoxically elevated in vitamin D deficiency (secondary hyperparathyroidism) - Not reliable for nutritional status
PTH (pg/mL)	20–100	15–80	12–70	10–60	- Diurnal variation: Peak 8 AM, nadir 4 PM - Draw early morning (8 AM) - Elevated in vitamin D deficiency, renal failure, calcium deficiency
Calcium (mg/dL)	8.5–10.5	8.8–10.6	8.9–10.7	8.9–10.8	- Minimal age variation after infancy - Must correct for albumin - Ionized calcium preferred: 1.1–1.3 mmol/L
Phosphate (mg/dL)	4.5–9.0	4.0–8.5	3.5–7.5	3.0–6.5	- Strongest age variation (highest in infants, declines with age) - Diurnal variation: afternoon nadir - Draw fasting, early morning
Alkaline phosphatase (IU/L)	150–600	180–650	160–570	140–480 IU/L	- Strongest age variation (peaks in infancy & puberty) - Sex-specific - Must use age/sex-specific reference ranges; adult ranges misleading

Note: Reference ranges given particularly those for pediatric patients, can differ significantly depending on the laboratory protocols, analyzer technology, reagents, methodology, calibration procedures & population differences used. The values provided here are approximate and should always be correlated with the specific validated reference intervals. For clinical decision making, it is essential to interpret results by referring to laboratory-specific, age-adjusted standards and universal cutoffs.

LABORATORY INTERPRETATION CHALLENGES OF KEY BIOMARKERS

1. Bone Turnover Markers

Bone turnover markers such as Alkaline Phosphatase (ALP), Procollagen Type 1 N-Terminal Propeptide (P1NP), and osteocalcin vary with age, sex, and pubertal stage, so pediatric values cannot be interpreted using adult reference ranges. ALP is normally higher during infancy and puberty because of active skeletal growth. The lack of standardized pediatric reference intervals makes it difficult to distinguish normal growth from rickets, osteomalacia, or other bone disease. Low ALP in a child with skeletal deformity should raise suspicion for hypophosphatasia.[16,17]

2. Vitamin D Assay Variability

While 25-hydroxyvitamin D [25(OH)D] is the standard biomarker for systemic vitamin D status, automated laboratory immunoassays suffer from significant inter-method variability and matrix interferences. Many commercial platforms fail to accurately differentiate between Vitamin D3 and D2. Furthermore, neonates possess high levels of an inactive structural epimer, 3-epi-25(OH)D3, which standard immunoassays misinterpret as active vitamin D. To prevent overestimating a neonate's true status, laboratories must utilize Liquid Chromatography-Mass Spectrometry (LC-MS/MS) to physically separate these compounds.[18]

3. Mineral Metabolism

Calcium and phosphate in children must be interpreted in the context of growth and renal maturation, because their normal ranges are not fixed like in adults. Total calcium can look low when albumin is reduced, even if biologically active calcium is normal, so corrected calcium equations are often unreliable in pediatrics. Ionized calcium is a better measure when hypocalcaemia is suspected because it reflects the physiologically active fraction. Phosphate levels also vary with age, and they can change during the day, which may lead to misleading results if the sample is taken later in the day. Morning fasting samples are preferred for more accurate assessment.[19]

4. Endocrine factors and Chronic Diseases

Parathyroid Hormone (PTH) is a short-lived marker and assay differences can affect results, especially in children with chronic kidney disease. Fibroblast Growth Factor 23 (FGF23) testing is also difficult because of limited pediatric reference ranges and assay variability. Chronic illnesses such as malabsorption, liver disease, obesity, and anticonvulsant use can alter vitamin D metabolism and confuse interpretation. Because of this, laboratory values must always be read together with clinical findings and the underlying disease context. Finally, pediatric DXA interpretation must utilize age and sex-matched adjusted for body size, as two-dimensional areal measurements frequently misdiagnose smaller children with falsely low bone density.[20]

Table 3 summarizes the key biochemical markers used in pediatric bone disorders and highlights why their interpretation is challenging in growing children. It shows the main physiologic role of each biomarker, the common laboratory pitfall, and the clinical message needed for accurate diagnosis. Together, these markers must be interpreted with age-specific reference ranges, assay awareness, and clinical context rather than in isolation.

Table 3: Key Biomarkers and Their Laboratory Interpretation Challenges In Pediatric Bone Disorders

Biomarker	Role in Pediatric Population	Primary Challenge	Clinical Implication
ALP[21]	Osteoblast activity, mineralization	Physiologic spikes in infancy/puberty	Must use age/sex-specific ranges
Calcium[22]	Neuromuscular stability, mineral balance	Albumin-dependent; corrected equations are inaccurate in children	Measure ionized calcium than normal calcium because of pseudohypocalcemia
Phosphate	Bone matrix substrate	Diurnal variation; higher in growing kids	Sample timing critical; evaluate TmP/GFR
25(OH)D[23]	Vitamin D status	C3-epimer cross-reactivity in infants	LC-MS/MS preferred for infants
$1,25(OH)_2D$	Hereditary rickets workup	Upregulated in deficiency (paradoxically normal/high)	Not reliable for nutritional status
PTH	Calcium/vitamin D regulation	Short half-life; assay variability	Concurrent 25(OH)D essential

SUPPLEMENTATION REGIMENS FOR VITAMIN D AND CALCIUM DEFICIENCY

Translating pediatric vitamin D diagnostic thresholds into clinical efficacy requires a careful balance between universal prophylaxis and targeted high-dose treatment. As per the recent Indian Academy of Pediatrics (IAP) Revised 2021 Guidelines evidencebased, agetailored regimens is recommended where infants (0–12 months) should receive routine vitamin D 400 IU/day, with therapeutic dosing for rickets at 2000 IU/day for 12 weeks (maintenance 400 IU/day); children >12 months are treated with 3000 IU/day for 12 weeks (alternative intermittent: five doses of 60,000 IU given fortnightly), followed by maintenance 600 IU/day. Always provide concomitant calcium (50–75 mg/kg/day, not exceeding 500 mg/day) during rickets therapy and ensure adequate dietary calcium thereafter. Use oral cholecalciferol (D3) as first line; reserve parenteral or active analogues (alfacalcidiol/calcitriol) for malabsorption or specific endocrine indications and avoid mega parenteral boluses as routine practice. Monitor response at about 12 weeks with serum calcium, phosphate, alkaline phosphatase and 25(OH)D and obtain radiographs at 4 and 12 weeks to document healing. check urine Ca/Cr and renal ultrasound if hypercalcemia or hypervitaminosis is suspected (urine Ca/Cr normal limits: <0.8 up to 6 mo, <0.6 at 6–12 mo, <0.2 ≥24 mo) and note that 25(OH)D <12 ng/mL = deficiency, 12–20 ng/mL = insufficiency, >20 ng/mL = sufficient while levels >100 ng/mL with hypercalcemia/hypercalciuria indicate toxicity.[3]

According to the recent ICMR-NIN Expert Committee, Dietary Guidelines for Indians-2024, vitamin D supplementation is recommended in children at risk of deficiency, while calcium supplementation may be required when dietary intake is inadequate or during periods of increased skeletal demand. Natural dietary sources rich in calcium include milk, yogurt, cheese, fortified dairy products, ragi (finger millet), sesame seeds, almonds, and green leafy vegetables. Vitamin D sources include sunlight exposure, fortified milk and cereals, egg yolk, fatty fish such as salmon and sardines, and fish liver oils. A balanced diet containing adequate protein, phosphorus, magnesium, and micronutrients, along with appropriate supplementation, helps prevent nutritional rickets and promotes healthy bone development in pediatric populations.[24,25]

ROLE OF HEALTH CARE PROFESSIONALS IN PEDIATRIC BONE DISORDERS

Managing pediatric vitamin D therapies requires a highly coordinated, multidisciplinary collaboration among physicians, nurses, and laboratory professionals to ensure safe and effective clinical outcomes. Physicians hold diagnostic and prescriptive accountability, evaluating clinical risk factors like hypotonia or prematurity to design individualized regimens, while dynamically adjusting dosages for complex comorbidities like obesity or chronic kidney disease. Health care professionals like nurses and laboratory professionals play an important role in early recognition and help to ensure timely investigations, treatment, and prevention of long-term skeletal complications. Table 4 summarises the early and red flag clinical features of pediatric bone disorders related to vitamin D and calcium deficiency. Early signs are often subtle and may include pain, weakness, irritability, poor growth, and mild skeletal changes, while red flag signs indicate more advanced disease with deformities, fractures, hypocalcemic symptoms, and neurological involvement.

Table 4: Early & Red Flag Signs of Pediatric Bone Disorders Associated[26]

Category	Signs
Early signs (mild/initial stage)	Bone pain, leg pain, mild muscle weakness, delayed motor milestones, irritability, fatigue, poor weight gain, decreased activity, sleep disturbances, slight wrist swelling, mild rachitic rosary, mild craniotabes and delayed tooth eruption.
Red flag signs (severe/advanced stage)	Bowed legs, pot-bellied appearance, pelvic deformity, chest deformities, skull softening, short stature, spontaneous fractures, tetany, muscle cramps, Chvostek sign (facial twitch sign), Trousseau sign (carpopedal spasm), cardiac symptoms, hypotonia, waddling gait, loss of motor skills, delayed walking, femoral bowing, spinal fractures, back pain, height loss, confusion, depression and seizure disorders.

Nurses serve as the frontline clinical interface, safely administering precise dosages, monitoring for immediate clinical signs of toxicity like hypercalcaemia, educating families on age-specific upper limits to prevent accidental overdose, and executing high-quality blood draws to protect sample integrity. Finally, laboratory professionals provide the objective, analytical foundation for these decisions by utilising high-precision methodologies to eliminate assay cross-reactivity, managing the broader bone metabolic panel, including critical functional co-markers like calcium, PTH, and ALP and executing rapid critical value notifications to alert the team before developing severe complications like nephrocalcinosis.[27]

CONCLUSION

Vitamin D-related bone disease in children is best interpreted as a metabolic pattern rather than a single laboratory value. Because serum 25-hydroxyvitamin D alone cannot show severity, duration, compensation, or cause, pattern recognition is vital. In rickets, a child may still present with normal calcium alongside low phosphate, high alkaline phosphatase, and elevated parathyroid hormone. Therefore, age-appropriate interpretation is far more useful than relying on a solitary cutoff. The lack of fully standardised pediatric decision limits means clinicians must combine biochemical results with radiology and clinical findings. Therefore, standardised pediatric reference ranges and interpretation that account for assay-specific characteristics are critical for achieving accurate diagnosis and effective monitoring to prevent complications. Hence, healthcare professionals play a major role in early recognition and timely intervention, which aids in promoting the progression of normal skeletal growth and mineralisation, thereby mitigating the risk of long-term skeletal deformities and fractures.

REFERENCES

1. Moon, R. J., Harvey, N. C., Davies, J. H., & Cooper, C. (2014). Vitamin D and skeletal health in infancy and childhood. Osteoporosis international: a journal established as result of cooperation between the European Foundation for Osteoporosis and the National Osteoporosis Foundation of the USA, 25(12), 2673–2684. https://doi.org/10.1007/s00198-014-2783-5
2. Palacios, C., & Gonzalez, L. (2014). Is vitamin D deficiency a major global public health problem?. The Journal of steroid biochemistry and molecular biology, 144 Pt A, 138–145. https://doi.org/10.1016/j.jsbmb.2013.11.003
3. Gupta, P., Dabas, A., Seth, A., Bhatia, V. L., Khadgawat, R., Kumar, P., Balasubramanian, S., Khadilkar, V., Mallikarjuna, H. B., Godbole, T., Krishnamurthy, S., Goyal, J. P., Bhakhri, B. K., Ahmad, A., Angadi, K., Basavaraj, G. V., Parekh, B. J., Kurpad, A., Marwaha, R. K., Shah, D., … Sachdev, H. P. S. (2022). Indian Academy of Pediatrics Revised (2021) Guidelines on Prevention and Treatment of Vitamin D Deficiency and Rickets. Indian pediatrics, 59(2), 142–158.
4. Kamboj, P., Dwivedi, S., & Toteja, G. S. (2018). Prevalence of hypovitaminosis D in India & way forward. The Indian journal of medical research, 148(5), 548–556. https://doi.org/10.4103/ijmr.IJMR_1807_18
5. Munns, C. F., Shaw, N., Kiely, M., Specker, B. L., Thacher, T. D., Ozono, K., Michigami, T., Tiosano, D., Mughal, M. Z., Mäkitie, O., Ramos-Abad, L., Ward, L., DiMeglio, L. A., Atapattu, N., Cassinelli, H., Braegger, C., Pettifor, J. M., Seth, A., Idris, H. W., Bhatia, V., … Högler, W. (2016). Global Consensus Recommendations on Prevention and Management of Nutritional Rickets. Hormone research in paediatrics, 85(2), 83–106. https://doi.org/10.1159/000443136
6. Vitamin D deficiency in children: An update on its prevalence, therapeutics and knowledge gaps. (n.d.). https://www.opensciencepublications.com/fulltextarticles/IJN-2395-2326-4-167.pdf
7. Pettifor J. M. (2014). Calcium and vitamin D metabolism in children in developing countries. Annals of nutrition & metabolism, 64 Suppl 2, 15–22. https://doi.org/10.1159/000365124
8. Allgrove, J. (2015). Calcium and bone disorders in children and adolescents. In Endocrine development. https://doi.org/10.1159/isbn.978-3-318-05467-5
9. Uday, S., & Högler, W. (2020). Nutritional rickets & osteomalacia: A practical approach to management. The Indian journal of medical research, 152(4), 356–367. https://doi.org/10.4103/ijmr.IJMR_1961_19
10. Rustico, S. E., Calabria, A. C., & Garber, S. J. (2014). Metabolic bone disease of prematurity. Journal of clinical & translational endocrinology, 1(3), 85–91. https://doi.org/10.1016/j.jcte.2014.06.004

11. Patel P, Hashmi MF. Chronic Kidney Disease-Mineral Bone Disorder (CKD-MBD) [Updated 2024 Apr 3]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2026 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK560742/

12. Abseyi, S. N., & Şıklar, Z. (2023). Approach to Rickets: Is It Calciopenic or Phosphopenic?. Turkish archives of pediatrics, 58(5), 458–466. https://doi.org/10.5152/TurkArchPediatr.2023.23050

13. Alsaif, S., Aljarbou, T., Alrahili, M., Alsherbini, L., Maghoula, M., Alluwaymi, A., Alsenani, M., Altuwaym, A., Alamer, F., Mandurah, A., Baylon, B., Alsehli, F., Ali, I., & Ali, K. (2025). Biochemical markers for metabolic bone disease in preterm infants: insights from a structured Bone Health Programme in the Middle East. BMJ paediatrics open, 9(1), e003927. https://doi.org/10.1136/bmjpo-2025-003927.

14. Corsello, A., Spolidoro, G. C. I., Milani, G. P., & Agostoni, C. (2023). Vitamin D in pediatric age: Current evidence, recommendations, and misunderstandings. Frontiers in medicine, 10, 1107855. https://doi.org/10.3389/fmed.2023.1107855.

15. Liju Yang, Vijaylaxmi Grey, Pediatric reference intervals for bone markers, Clinical Biochemistry, Volume 39, Issue 6, 2006, Pages 561-568, ISSN 0009-9120, https://doi.org/10.1016/j.clinbiochem.2005.11.015.

16. Shao, J., Zhou, S. S., Qu, Y., Liang, B. B., Yu, Q. H., & Wu, J. (2020). Correlation between bone turnover and metabolic markers with age and gender: a cross-sectional study of hospital information system data. BMC musculoskeletal disorders, 21(1), 603. https://doi.org/10.1186/s12891-020-03610-w

17. Weitzmann, M. N., & Ofotokun, I. (2016). Physiological and pathophysiological bone turnover - role of the immune system. Nature reviews. Endocrinology, 12(9), 518–532. https://doi.org/10.1038/nrendo.2016.91

18. Sempos, C. T., & Binkley, N. (2020). 25-Hydroxyvitamin D assay standardisation and vitamin D guidelines paralysis. Public health nutrition, 23(7), 1153–1164. https://doi.org/10.1017/S1368980019005251

19. Hu, Z. D., Huang, Y. L., Wang, M. Y., Hu, G. J., & Han, Y. Q. (2018). Predictive accuracy of serum total calcium for both critically high and critically low ionized calcium in critical illness. Journal of clinical laboratory analysis, 32(9), e22589. https://doi.org/10.1002/jcla.22589

20. Binkovitz, L. A., & Henwood, M. J. (2007). Pediatric DXA: technique and interpretation. Pediatric radiology, 37(1), 21–31. https://doi.org/10.1007/s00247-006-0153-y

21. Jacqueline-Michéle Strauch, Mandy Vogel, Christof Meigen, Uta Ceglarek, Jürgen Kratzsch, Anja Willenberg, Wieland Kiess, Pediatric reference values of alkaline phosphatase: Analysis from a German population-based cohort and influence of anthropometric and blood parameters, Bone, Volume 174, 2023, 116809, ISSN 8756-3282, https://doi.org/10.1016/j.bone.2023.116809.

22. Bharill, S., & Wu, M. (2023). Hypocalcemia and Hypercalcemia in Children. Pediatrics in review, 44(9), 533–536. https://doi.org/10.1542/pir.2022-005578

23. Singh, R. J., Taylor, R. L., Reddy, G. S., & Grebe, S. K. (2006). C-3 epimers can account for a significant proportion of total circulating 25-hydroxyvitamin D in infants, complicating accurate measurement and interpretation of vitamin D status. The Journal of clinical endocrinology and metabolism, 91(8), 3055–3061. https://doi.org/10.1210/jc.2006-0710

24. ICMR-NIN Expert Committee, Dietary Guidelines for Indians-2024.

25. Prevention and treatment of vitamin D and calcium deficiency in children and adolescents: Indian Academy of Pediatrics (IAP) guidelines. (n.d.). https://www.indianpediatrics.net/july2017/july-567-573.htm

26. Event. (2026, May 22). Early signs of rare bone conditions in children and adults. Dr. Umesh Jadhav. https://drumeshjadhav.com/early-signs-of-rare-bone-conditions-in-children-and-adults/

27. Rodd, C., Kirouac, N., Orkin, J., & Grimes, R. (2022). Evaluating and optimizing bone health in children with chronic health conditions. Paediatrics & child health, 27(4), 232–242. https://doi.org/10.1093/pch/pxac036