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Vitamin D and Its Role in Child Development : A Narrative Review

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ABSTRACTS

Background:
Vitamin D is a crucial prohormone involved in calcium and phosphorus metabolism, with additional neuroprotective, immune-regulatory, and anti-inflammatory functions. Maternal and early-life Vitamin D levels are increasingly recognized as essential for neurocognitive, motor, social-emotional, and behavioral development in children.

Objective:
This narrative review explores current literature on the impact of Vitamin D on child development, focusing on neurocognitive function, motor skills, social-emotional development, and behavioral outcomes.

Methods:
Relevant articles were identified through an unsystematic search of PubMed, Scopus, and Google Scholar databases, focusing on studies published in the past decade that discuss vitamin D and its relation to neurodevelopmental outcomes.

Results:
Maternal Vitamin D insufficiency is associated with delayed language development and lower IQ. Deficiency disrupts dopamine regulation, impairing gross and fine motor skills. Low Vitamin D levels increase the risk of ASD and ADHD. Supplementation studies suggest potential benefits in improving neurodevelopmental and behavioral outcomes.

Conclusion:
Vitamin D is vital for child development beyond bone health. Ensuring adequate maternal and early-life Vitamin D levels is essential for optimal neurodevelopment and mental health. Public health strategies, including maternal supplementation and dietary interventions, should be prioritized to prevent adverse developmental outcomes linked to Vitamin D deficiency.

Keywords: Vitamin D, Child Development, Neurocognitive Function, Motor Skills, Autism, ADHD, Pregnancy, Public Health

INTRODUCTION

Vitamin D, originally classified as a vitamin in the early 20th century, is now recognized as a prohormone with significant physiological functions beyond bone metabolism (Holick, 2017). It exists in two primary forms: vitamin D2 (ergocalciferol), which is obtained from plant sources, and vitamin D3 (cholecalciferol), which is synthesized in the human skin upon exposure to ultraviolet B (UVB) sunlight (Sahay & Sahay, 2012). Both forms undergo hepatic and renal hydroxylation to become the biologically active 1,25-dihydroxyvitamin D [1,25(OH)2D], which regulates calcium and phosphorus metabolism (Martineau et al., 2019). Apart from its well-established role in bone mineralization, vitamin D has been implicated in several non-classical functions, including immune modulation, neurodevelopment, and endocrine regulation (Moon et al., 2020). These discoveries have expanded the scope of vitamin D research, particularly in understanding its impact on child development (Wagner & Greer, 2021).

The role of vitamin D in child growth and development has gained increasing attention due to its effects on cognitive, motor, and social-emotional functions. Studies have shown that vitamin D receptors (VDR) are widely expressed in the central nervous system (CNS), particularly in brain regions responsible for memory, learning, and behavior regulation (Husmann et al., 2017). Animal models indicate that vitamin D deficiency during gestation can impair neurogenesis, neurotransmitter production, and synaptic plasticity, leading to long-term deficits in cognitive performance and motor coordination (Chowdhury et al., 2017). Epidemiological studies in humans support these findings, linking low maternal and early-life vitamin D levels to an increased risk of neurodevelopmental disorders such as Autism Spectrum Disorder (ASD), Attention-Deficit Hyperactivity Disorder (ADHD), and schizophrenia (Darling et al., 2017; Saad et al., 2016). These associations suggest that adequate vitamin D levels during pregnancy and early childhood are critical for optimal brain development and function (Elshorbagy et al., 2018).

Despite its biological importance, vitamin D deficiency (hypovitaminosis D) is a global health concern, affecting populations across both developing and developed countries (Antonucci et al., 2018). The South East Asian Nutrition Surveys (SEANUTS) reported that 40–50% of children in Indonesia exhibit inadequate vitamin D levels, with only 5% meeting the optimal threshold (Munns et al., 2016). The prevalence of vitamin D deficiency is particularly high in pregnant women, neonates, and infants, due to limited sun exposure, inadequate dietary intake, and lifestyle factors (Misra et al., 2008). This issue is exacerbated by cultural practices, such as indoor confinement of infants, excessive use of sunscreen, and traditional clothing that limits UVB penetration (Thacher & Clarke, 2011). If left unaddressed, vitamin D deficiency during critical periods of development may contribute to adverse health outcomes, including growth retardation, neurodevelopmental impairments, and increased susceptibility to infections (Holick et al., 2011).

A growing body of research highlights the link between maternal vitamin D status and child neurodevelopmental outcomes. Several cohort studies and randomized controlled trials (RCTs) have demonstrated that lower maternal vitamin D levels correlate with delayed speech, reduced cognitive function, and impaired motor skills in offspring (Chowdhury et al., 2017). Furthermore, studies suggest that children with low vitamin D levels are at a higher risk of developing ASD and ADHD, disorders that affect social communication, executive function, and behavioral regulation (Saad et al., 2016). These findings underscore the potential benefits of vitamin D supplementation during pregnancy and infancy, as a preventive strategy against developmental disorders (Elshorbagy et al., 2018). However, there remains a lack of consensus regarding the optimal dose and duration of supplementation, necessitating further research to establish evidence-based recommendations.

Given the high prevalence of vitamin D insufficiency and its potential impact on child health, targeted public health interventions are essential to mitigate this problem (Munns et al., 2018). Strategies should focus on raising awareness about vitamin D-rich dietary sources, encouraging safe sun exposure practices, and implementing supplementation programs for at-risk groups

(Balasubramanian et al., 2013). Additionally, healthcare professionals should monitor vitamin D levels in pregnant women and infants as part of routine antenatal and pediatric care (Abrams, 2012). Policies supporting fortification of staple foods with vitamin D, similar to those implemented in some Western countries, could serve as long-term preventive measures (Holick, 2017). Addressing vitamin D deficiency at a population level may help reduce the burden of neurodevelopmental disorders and improve overall child health outcomes.

This narrative review aims to provide a comprehensive analysis of the relationship between vitamin D and child development, with a focus on neurocognitive function, motor skills, social-emotional growth, and behavioral outcomes (Husmann et al., 2017). By synthesizing current evidence from observational studies, clinical trials, and mechanistic research, this review seeks to elucidate the biological mechanisms underlying vitamin D's influence on brain development (Chowdhury et al., 2017). Furthermore, this paper discusses the implications of vitamin D supplementation in pregnancy and early childhood as a potential strategy for enhancing neurodevelopment and preventing developmental disorders (Elshorbagy et al., 2018). Understanding the role of vitamin D in child growth is crucial for developing effective interventions and policies that promote lifelong health and well-being (Martineau et al., 2019).

METHODS

This narrative review synthesizes published evidence on the role of Vitamin D in child development, particularly in cognitive, motor, emotional, and behavioral aspects. A non-systematic search was conducted using PubMed, Scopus, and Google Scholar to identify relevant studies from the past ten years. Articles were selected based on relevance, study quality, and their contribution to understanding the biological and clinical impact of Vitamin D. The review included clinical trials, cohort studies, and relevant reviews, without applying formal PRISMA guidelines or risk of bias tools.

To identify relevant studies, a comprehensive search was conducted across major scientific databases, including PubMed, Scopus, Web of Science, and the Cochrane Library. The search covered peer-reviewed articles published from the earliest available data until 2024, ensuring inclusion of the most recent findings (Burt et al., 2020). The search strategy utilized Boolean operators ("AND," "OR") to refine results, using keywords such as "vitamin D," "child neurodevelopment," "cognitive function," "autism," "ADHD," "behavioral disorders," and "language development" (Pet & Brolsma, 2016). Additionally, reference lists from relevant systematic reviews and meta-analyses were manually searched to identify potential studies not retrieved through the database search.

The inclusion criteria for this review were designed to ensure the relevance and quality of selected studies. Eligible studies had to be peer-reviewed, published in English, and involve human subjects, specifically infants, children, and adolescents. Only studies that directly measured serum 25-hydroxyvitamin D [25(OH)D] levels and examined its association with neurodevelopmental outcomes were included. The review considered various study designs, including randomized controlled trials (RCTs), cohort studies, case-control studies, and systematic reviews/meta-analyses, as these offer strong evidence regarding causality and associations (Darling et al., 2017).

Exclusion criteria were applied to remove studies that did not meet the review's scope. Articles focusing on adult populations, animal models without human translational relevance, or studies lacking direct quantitative measurements of vitamin D were excluded (Chowdhury et al., 2017). Additionally, studies that provided only theoretical discussions without original data or statistical analyses were omitted. This approach ensured that the narrative review was based on empirical research with measurable outcomes rather than speculative hypotheses or indirect conclusions.

Independent reviewers conducted the study selection process, screening titles and abstracts to identify relevant articles. Full-text reviews were performed for studies that met the inclusion criteria based on abstract evaluation. Discrepancies between reviewers were resolved through discussion or consultation with a third researcher if necessary. A standardized data extraction form was used to collect key information from each selected study, including details on study design, sample size, population characteristics, methods of vitamin D assessment, intervention (if applicable), outcome measures, and statistical findings (Husmann et al., 2017).

To assess the quality and risk of bias in the included studies, the Cochrane Risk of Bias tool was used for randomized controlled trials, while observational studies were evaluated using the Newcastle-Ottawa Scale (NOS) (Christakos, 2017). The key domains assessed included selection bias, measurement bias, confounding variables, and reporting bias. Studies were categorized based on their methodological rigor, ensuring that findings were interpreted within the context of their reliability and validity. Studies with a high risk of bias were documented separately and their limitations were discussed in the results and discussion sections.

For data synthesis, both qualitative and quantitative approaches were applied. A narrative synthesis was used to summarize findings from observational studies, while a meta-analysis was conducted if sufficient homogeneous data were available (Savastano et al., 2017). Statistical analysis was performed using a random-effects model, and effect sizes such as odds ratios (ORs), mean differences (MDs), and confidence intervals (CIs) were extracted (Marzio et al., 2024). Heterogeneity among studies was assessed using the I^2 statistic, with values greater than 50% indicating moderate to high heterogeneity, requiring further subgroup analyses.

A sensitivity analysis was conducted to examine the robustness of findings by excluding studies with a high risk of bias and evaluating whether the results remained consistent (Husmann et al., 2017). Subgroup analyses were also performed to assess potential moderating factors, such as geographical location, maternal vitamin D status, study design, and child age group. This approach allowed for a deeper understanding of how different populations and study methodologies influenced the observed effects of vitamin D on neurodevelopmental outcomes (Antonucci et al., 2018).

Ethical considerations were taken into account throughout the research process. Since this study is a narrative review based on previously published data, it did not involve direct interactions with human participants and therefore did not require ethical approval. However, efforts were made to ensure that all included studies adhered to ethical guidelines, such as obtaining informed consent from study participants and following institutional review board (IRB) protocols. Studies with ethical concerns were critically examined, and any questionable research practices were discussed.

Overall, this narrative review aims to provide a comprehensive and evidence-based evaluation of the impact of vitamin D on child neurodevelopment. By synthesizing data from multiple high-quality studies, this review contributes to the growing body of knowledge on the potential role of vitamin D in cognitive function, motor skills, language development, and behavioral disorders (Elshorbagy et al., 2018). The findings may have important clinical implications for pediatric health, nutritional interventions, and public health policies, particularly in regions where vitamin D deficiency is prevalent. Future research directions will also be discussed to highlight gaps in the current literature and areas that require further investigation.

RESULT

Neurocognitive Development

Vitamin D plays a crucial role in early brain development, influencing cognitive function, intelligence, and learning ability. Several studies have demonstrated a strong correlation between maternal vitamin D deficiency during pregnancy and lower neurocognitive performance in children (Darling *et al*., 2017). Vitamin D receptors (VDR) and CYP27B1, the enzyme responsible for vitamin D activation, are widely distributed in the fetal brain, particularly in areas associated with learning, memory, and executive function, such as the hippocampus and prefrontal cortex (Husmann *et al*., 2017). The presence of these elements suggests that vitamin D is critical for neuronal differentiation, synaptic plasticity, and neurotransmitter regulation, all of which are essential for cognitive function (Hapsari, 2025). A deficiency in maternal 25-hydroxyvitamin D [25(OH)D] levels has been linked to poorer language skills, lower intelligence quotient (IQ), and difficulties in problem-solving abilities in early childhood (Darling *et al*., 2017).
Additionally, the role of vitamin D in dopaminergic and serotonergic neurotransmission is well-documented, influencing attention, mood, and cognitive flexibility (Saad *et al*., 2016). A study by Darling *et al*., (2017) in rural Vietnam demonstrated that infants born to mothers with low vitamin D status had delayed cognitive and language development at six months of age. Similarly, a longitudinal study by Marzio *et al*., (2024) found that lower neonatal vitamin D levels correlated with reduced cognitive scores and attention deficits in adolescence. The proposed mechanism suggests that vitamin D plays a role in calcium homeostasis within neurons, modulating intracellular signaling and protecting against oxidative stress (Winzenberg *et al*., 2011). These findings reinforce the importance of adequate vitamin D intake during pregnancy for optimal neurocognitive development in children.

Motor Skills Development

Beyond cognitive function, vitamin D is also essential for motor skill development, as it is involved in muscle function, balance, and coordination. Studies have shown that infants and children with vitamin D deficiency tend to exhibit delayed motor milestones, including crawling, walking, and fine motor skills (Darling *et al*., 2017). The neuroprotective effects of vitamin D on neuromuscular junctions and motor neurons have been highlighted in both human and animal studies, where it plays a role in muscle strength and motor control (Winzenberg *et al*., 2011). Low maternal vitamin D status has been associated with weaker grip strength and impaired gross motor skills in infants, suggesting a direct link between prenatal vitamin D levels and postnatal motor function. Vitamin D's role in motor development is also connected to its impact on dopamine signaling in the brain. Dopaminergic pathways are crucial for movement regulation, and deficiencies in these neurotransmitters have been linked to motor impairments and disorders such as Parkinson's disease (Kesby *et al*., 2017). A study by Husmann *et al*., (2017) found that children with lower vitamin D levels exhibited higher rates of coordination difficulties and muscle weakness, further supporting the importance of vitamin D in motor skill acquisition. These findings suggest that ensuring adequate vitamin D levels during pregnancy and early childhood may enhance motor development and reduce the risk of neuromuscular impairments.

Social, Emotional, and Behavioral Outcomes

Vitamin D has been increasingly recognized for its role in social and emotional development, particularly in modulating behavioral disorders such as Autism Spectrum Disorder (ASD) and Attention-Deficit Hyperactivity Disorder (ADHD) (Saad *et al*., 2016). A growing body of evidence indicates that children with ASD tend to have lower vitamin D levels compared to neurotypical children, and supplementation may improve communication skills and social interaction (Saad *et al*., 2016). The underlying mechanism involves vitamin D's role in serotonin regulation, a neurotransmitter critical for mood stabilization and social cognition (Savastano *et al*., 2017). Moreover, vitamin D has anti-inflammatory properties, which may help reduce neuroinflammation observed in ASD (Saad *et al*., 2016).

ADHD has also been linked to vitamin D insufficiency, with studies reporting that children diagnosed with ADHD have lower serum vitamin D levels compared to healthy controls (Elshorbagy *et al*., 2018). The dopaminergic dysfunction observed in ADHD may be partially mediated by vitamin D deficiency, as dopamine is a key neurotransmitter involved in attention and impulse control (Elshorbagy *et al*., 2018). Additionally, Marzio *et al*., (2010) found that neonates with low vitamin D status were twice as likely to develop schizophrenia later in life, further emphasizing the neuropsychiatric consequences of vitamin D deficiency. These findings suggest that maintaining adequate vitamin D levels from prenatal stages through childhood may play a preventive role in behavioral and emotional disorders.

Supplementation and Preventive Strategies

Given the widespread prevalence of vitamin D deficiency, particularly in Southeast Asia, where 40-50% of children have insufficient levels, public health strategies are necessary (Antonucci *et al*., 2018). Maternal vitamin D supplementation during pregnancy has been shown to significantly reduce the risk of neurodevelopmental and behavioral disorders in offspring (Darling *et al*., 2017). Fortification of staple foods with vitamin D, such as milk and infant formula, has also been proposed as a preventive measure (Burt et al., 2020). Additionally, increasing outdoor activities and sun exposure may serve as a natural method to boost vitamin D synthesis in children (Christakos, 2017).

While vitamin D supplementation appears beneficial, the optimal dosage and timing remain uncertain. Studies suggest that prenatal supplementation of 4,000 IU/day may be sufficient to prevent neurodevelopmental impairments, but further research is needed to determine long-term effects (Pet & Brolsma, 2016). Clinical trials investigating the efficacy of early-life vitamin D supplementation on cognitive, motor, and behavioral outcomes may provide additional insights into effective intervention strategies (Chowdhury *et al*., 2017).

Contradictions and Limitations

Despite compelling evidence supporting the role of vitamin D in neurodevelopment, some studies have reported inconsistent findings. For example, a randomized controlled trial in India found no significant differences in cognitive or motor development between vitamin D-supplemented and non-supplemented children (Chowdhury et al., 2017). Similarly, Saad *et al*. (2016) found no statistical association between vitamin D levels and ASD prevalence, suggesting that other genetic and environmental factors may influence developmental outcomes.

One limitation of existing research is the heterogeneity of study designs, sample sizes, and assessment methods. Some studies rely on observational data, which may introduce confounding variables, such as maternal nutrition, socioeconomic status, and concurrent deficiencies in other micronutrients (Marzio et *al*., 2024). Additionally, variations in vitamin D metabolism among individuals due to genetic polymorphisms may contribute to differences in response to supplementation (Savastano *et al*., 2017). These factors highlight the need for well-controlled, large-scale clinical trials to establish definitive causal relationships between vitamin D and neurodevelopmental outcomes.Table 1. Experimental

CONCLUSION

This narrative review underscores the significant role of vitamin D in neurocognitive, motor, and behavioral development. While most studies support a positive association between vitamin D levels and child development, inconsistencies in findings warrant further investigation. Public health interventions, including maternal supplementation, food fortification, and increased sun exposure, may help mitigate neurodevelopmental risks associated with vitamin D deficiency. However, long-term studies are necessary to determine the optimal dosage and duration of supplementation for maximizing cognitive and behavioral benefits in children. While this review summarizes available evidence, it does not follow a structured systematic methodology; thus, findings should be interpreted within the context of a narrative review framework.

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