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Review Article

Biological Influences on Early Childhood Caries: The Interplay Between Oral Microbiome and Vitamin-D

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Abstract
Early childhood caries (ECC) is recognized as a multifactorial condition resulting from a complex interaction of biological, environmental, and behavioral determinants. Among the biological factors, particular emphasis has been placed on the structure and dynamics of the oral microbiome and the systemic influence of vitamin D. This review examines the interrelationship between oral microbial communities especially Streptococcus mutans and other cariogenic organisms and vitamin D levels in the etiology of ECC. The oral microbiota establishes during infancy and is shaped by dietary habits, oral hygiene, host immune responses, and maternal transmission. Vitamin D, beyond its established role in maintaining calcium and phosphate balance, plays a crucial part in modulating innate immunity and stimulating antimicrobial peptide production, which can influence microbial adherence and biofilm development. A deficiency in vitamin D has been linked to enamel hypoplasia and an increased predisposition to dental caries. Gaining insight into the ways vitamin D affects the host microbiome interface within the oral environment may provide new avenues for preventive measures and therapeutic strategies targeting ECC. This review underscores the importance of adopting integrative approaches that address both microbial ecology and nutritional status to effectively manage and prevent early childhood caries.

Keywords: *Early Childhood Caries; Oral microbiome; Vitamin D; Enamel hypoplasia.*

INTRODUCTION AND BACKGROUND

Dental caries is among the most widespread yet preventable noncommunicable diseases, affecting the hard structures of teeth. It is characterized by the degradation of organic matter and the demineralization of inorganic components. This pathological process occurs when the normally stable oral biofilm undergoes a shift towards an acidogenic, aciduric, and cariogenic microbial community primarily driven by frequent intake of dietary sugars.[1]

Early Childhood Caries (ECC) remains one of the most common chronic conditions in young children globally, exerting profound effects on their growth, nutrition, speech development, and overall quality of life.[2] ECC is defined as the presence of one or more decayed, missing (due to caries), or filled surfaces in any primary tooth of a child younger than six years. Although excessive sugar intake and inadequate oral hygiene have traditionally been viewed as major contributors, emerging research highlights the significant influence of biological factors particularly the oral microbiome and vitamin D levels in the onset and progression of ECC.[3]

The oral microbiome encompasses the complex community of microorganisms inhabiting the oral cavity. Colonization of this microbial ecosystem begins shortly after birth and undergoes significant development during early childhood, influenced by factors such as delivery method, breastfeeding practices, antibiotic use, and environmental exposures.[4] A balanced and diverse oral microbiota is indicative of oral health; however, frequent consumption of dietary sugars and poor oral hygiene can disrupt this equilibrium. Such disturbances lead to microbial dysbiosis, where acid-producing and acid-tolerant species like *Streptococcus mutans* proliferate. These bacteria metabolize fermentable carbohydrates into lactic acid, reducing the pH within dental plaque and initiating demineralization of enamel and dentin ultimately resulting in dental caries.[5]

At the same time, vitamin D has emerged as a pivotal contributor to both oral and systemic health. It is vital for maintaining calcium and phosphate balance, which is essential for the proper mineralization of dental hard tissues like enamel and dentin. Deficiencies in maternal or early childhood vitamin D have been linked to enamel hypoplasia a developmental anomaly that weakens enamel structure and heightens caries risk. [7] Additionally, vitamin D exhibits immunomodulatory effects by stimulating the production of antimicrobial peptides such as cathelicidins and defensins. These peptides strengthen innate immunity by directly targeting cariogenic microorganisms.[8]

The relationship between vitamin D and the oral microbiome is intricate and reciprocal. Emerging evidence indicates that vitamin D can influence the diversity and stability of oral microbial communities by regulating host immune responses and maintaining epithelial barrier function.[9] In contrast, the oral microbiota itself may impact vitamin D metabolism, either through microbial enzymatic activities affecting vitamin D pathways or via inflammation-mediated changes in vitamin D receptor expression.[10]

Appreciating this bidirectional interaction underscores the importance of moving beyond traditional mechanical methods for ECC prevention. A more holistic approach should address biological risk factors such as vitamin D deficiency and microbial dysbiosis. Potential adjunctive strategies include maternal and early childhood vitamin D supplementation, probiotic administration, and early life monitoring of oral microbial populations to support ECC prevention and management.[11]

DISCUSSION

1. The Role of the Oral Microbiome in Early Childhood Caries

The oral microbiome is fundamental to sustaining oral health by ensuring microbial diversity and ecological stability.[5] In early childhood, however, this balance is particularly susceptible to external factors such as dietary habits especially frequent sugar consumption and antibiotic exposure.[4]

Regular intake of fermentable carbohydrates promotes the dominance of acidogenic and aciduric species like *Streptococcus mutans*, shifting the microbial composition toward a cariogenic biofilm.[5] These microorganisms ferment sugars to produce organic acids, notably lactic acid, which significantly reduce plaque pH.[3] Such acidic conditions facilitate enamel and dentin demineralization, leading to the onset of early carious lesions.[1]

2. The Role of Vitamin D in Dental Health and Caries Susceptibility

Vitamin D is critical for maintaining calcium and phosphate balance, both of which are vital for the proper mineralization of enamel and dentin.[6] Insufficient levels of vitamin D during prenatal or early childhood stages can lead to enamel hypoplasia characterized by thin, inadequately mineralized enamel that is highly vulnerable to acid-induced damage.[7] Additionally, vitamin D influences immune function by inducing the synthesis of antimicrobial peptides such as cathelicidins and defensins.[8] These peptides not only combat cariogenic microbes directly but also reinforce the oral epithelial barrier, reducing the likelihood of infection and microbial imbalance.[9] As a result, vitamin D deficiency compromises both structural integrity and immunological defenses, increasing susceptibility to ECC.[6]

3. Interactions between the Oral Microbiome and Vitamin D

Recent studies have revealed a sophisticated, bidirectional relationship between vitamin D status and the oral microbiome, which may play a crucial role in determining the risk and severity of early childhood caries (ECC).[12,13] Adequate vitamin D levels contribute to oral health by enhancing epithelial barrier integrity and promoting the production of antimicrobial peptides, including cathelicidins and defensins. These peptides strengthen mucosal immunity, creating a hostile environment for cariogenic organisms. Vitamin D also supports epithelial cell renewal and structural stability, reducing susceptibility to microbial colonization and invasion.[14,15]

Additionally, vitamin D modulates immune responses by downregulating pro-inflammatory cytokines while encouraging anti-inflammatory pathways, thereby helping maintain microbial homeostasis in the oral cavity.[12,14]

Conversely, a dysbiotic oral microbiome marked by diminished microbial diversity and overgrowth of acidogenic species such as *Streptococcus mutans* can adversely affect vitamin D metabolism.[13,16] Certain pathogenic bacteria have been

shown to downregulate the expression of vitamin D receptors (VDR) in oral epithelial cells, weakening the tissue's responsiveness to circulating vitamin D.[13,17] Reduced VDR expression diminishes the effectiveness of Vitamin D's antimicrobial and immunomodulatory actions, exacerbating microbial imbalance.[12,17] Furthermore, enzymatic activity from pathogenic microbes may disrupt vitamin D hydroxylation processes, thereby affecting its activation and bioavailability.[13]

This dynamic interaction creates a feedback loop: vitamin D deficiency compromises immune regulation of the oral microbiota, while dysbiosis further impairs vitamin D pathways, amplifying ECC risk.[12,13] Children with inadequate vitamin D may exhibit weakened innate immunity and defective enamel formation, increasing their vulnerability to early microbial colonization and carious lesion development.[18,19] Consequently, prevention strategies that focus solely on mechanical plaque removal or sugar restriction may overlook key biological risk factors.[20] Integrating approaches such as vitamin D supplementation, probiotic therapy, early microbial assessment, and immune support could provide a more comprehensive strategy for ECC prevention and management.[21]

4. Clinical and Preventive Implications

The intricate relationship between the oral microbiome and vitamin D highlights the importance of adopting a multidimensional strategy for preventing early childhood caries (ECC).[11] Conventional methods that emphasize mechanical plaque control and dietary advice alone may fall short, particularly in high-risk groups.[3] Identifying and addressing vitamin D deficiency in pregnant women and young children could be a crucial step toward mitigating biological vulnerabilities associated with ECC.[7]

Maternal and pediatric vitamin D supplementation has the potential to lower the prevalence of enamel developmental defects and enhance immune defense mechanisms.[6] Additionally, the use of probiotics and prebiotics may support the reestablishment of microbial balance and inhibit the formation of cariogenic biofilms.[4] Incorporating these biological factors into public health initiatives could play a pivotal role in reducing the overall burden of ECC and improving oral health outcomes.[1]

In summary, ECC should be approached not merely as a disease of neglect, but as a condition arising from a complex interplay of biological systems. Recognizing the roles of the oral microbiome and vitamin D in ECC pathogenesis allows for a more holistic, individualized, and potentially more effective approach to caries prevention in young children. Future clinical strategies should emphasize early-life interventions, maternal-child health integration, and biological risk assessment in dental care protocols to address this pervasive and impactful condition.

CONCLUSION

In conclusion, the interplay between the oral microbiome and vitamin D constitutes a significant biological influence on ECC. Maintaining optimal vitamin D levels through dietary sources, supplementation, and sunlight exposure may help regulate microbial balance and support enamel integrity. Understanding these biological mechanisms provides new insights into ECC prevention strategies beyond mechanical plaque control and dietary counseling.

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