CARIES DISEASE: PATHOGENESIS, MODERN TREATMENT METHODS AND PREVENTIVE MEASURES

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Abstract. This article provides a comprehensive overview of the pathogenesis of dental caries, its modern treatment methods, and current preventive strategies. It emphasizes the multifactorial nature of caries as a dynamic process involving microbial activity, host susceptibility, dietary factors, and time. The paper discusses both invasive and non-invasive management options, such as remineralization techniques, minimal intervention dentistry, bioactive materials, and photodynamic therapy. Preventive approaches—including fluoride application, dietary control, oral hygiene education, and risk-based strategies—are examined for their effectiveness in reducing the incidence and severity of caries. The article underscores the importance of personalized dental care and early detection as key components in minimizing the global burden of this widespread disease.

Keywords: Dental caries; pathogenesis; remineralization; bioactive materials; prevention; oral health; fluoride; minimal intervention; photodynamic therapy.

INTRODUCTION

Dental caries remains one of the most prevalent chronic diseases affecting human populations worldwide. It affects individuals of all ages, socioeconomic statuses, and geographic locations, posing a significant public health burden. Despite major advancements in dental care and awareness campaigns, the global incidence of dental caries continues to be high, particularly in developing regions and among disadvantaged populations [1]. Caries is not merely a cosmetic issue but a complex disease that, if left untreated, can lead to pain, infection, tooth loss, and systemic health complications. Understanding the multifactorial pathogenesis of dental caries, along with modern approaches to its treatment and prevention, is essential for improving individual oral health and reducing healthcare costs on a national scale.

MATERIALS AND METHODS

The pathogenesis of dental caries involves the interaction between host factors, dietary habits, oral microbiota, and time. Caries begins when acid-producing bacteria in the dental biofilm metabolize fermentable carbohydrates, primarily sucrose, leading to acid production. These acids gradually demineralize the enamel and dentin, initiating the formation of carious lesions [2].

Streptococcus mutans and Lactobacillus species are considered the primary pathogens responsible for initiating and progressing carious lesions. However, caries is increasingly understood as a polymicrobial disease, where a diverse microbial community contributes to the imbalance between demineralization and remineralization processes. The pH of the oral environment, frequency of sugar intake, saliva flow and composition, enamel quality, and immune responses are all critical host factors that influence the development and progression of caries.

The disease follows a dynamic process, with periods of demineralization and remineralization occurring continuously. If this balance tips in favor of demineralization and is sustained over time, irreversible damage occurs, forming cavities that require professional intervention. Caries may begin as a non-cavitated white spot lesion and progress through enamel into dentin and eventually into the pulp, resulting in pain and potential systemic infection if left untreated.

RESULTS AND DISCUSSION

Contemporary treatment strategies for dental caries have evolved from traditional "drill and fill" approaches to more conservative, minimally invasive, and patient-centered care. The core philosophy now emphasizes preserving tooth structure and restoring the natural balance of the oral environment [3].

In the early stages of caries, non-invasive remineralization treatments are often preferred. These include the use of topical fluorides, such as fluoride varnishes and gels, as well as calcium phosphate compounds like CPP-ACP (casein phosphopeptide-amorphous calcium phosphate). These agents enhance remineralization of early enamel lesions and prevent progression.

Silver diamine fluoride (SDF) has emerged as a powerful non-invasive option that both halts caries progression and provides antibacterial action. It is particularly effective in pediatric and geriatric populations where traditional restorative treatments may be challenging.

When restoration is necessary, techniques such as Atraumatic Restorative Treatment (ART) and air abrasion minimize the removal of healthy tooth tissue. These approaches align with the principles of minimally invasive dentistry and have been successfully applied in community-based and resource-limited settings.

Adhesive materials like glass ionomer cements, which release fluoride, are often used in modern restorative dentistry to both fill the cavity and offer ongoing protection against future decay. Resin-based composites are also widely used for their aesthetic and functional advantages.

The development of bioactive restorative materials marks a significant advancement. These materials interact with the tooth structure and oral fluids to encourage remineralization, seal dentinal tubules, and even respond to bacterial

activity. Examples include bioactive glass, self-healing composites, and materials incorporating antibacterial agents like chlorhexidine or silver nanoparticles [4].

Laser technology is increasingly used for both caries detection and treatment. Diode and Er:YAG lasers can remove decayed tissue with minimal discomfort and preserve more healthy enamel and dentin. Photodynamic therapy (PDT), involving light-sensitive agents and a light source, is also being explored for its antimicrobial effects in caries management.

In recent years, researchers have moved beyond the traditional "specific plaque hypothesis," which identified a few bacterial species as the primary culprits in caries development. Instead, the ecological plaque hypothesis has gained traction. According to this model, dental caries results not from a specific pathogen, but from a shift in the balance of the entire oral microbiome, often caused by repeated acidification due to frequent sugar intake.

This microbial dysbiosis promotes the dominance of aciduric and acidogenic species such as Streptococcus mutans, Lactobacillus acidophilus, and Bifidobacteria. These bacteria thrive in low pH environments and exacerbate demineralization. The change is not only in the type of bacteria but in their behavior—gene expression and metabolism adapt to the new environment, making early interventions crucial to prevent irreversible damage.

Saliva plays a critical role in oral defense through several mechanisms: it acts as a buffer against acid, facilitates the clearance of food debris and microorganisms, and provides ions (calcium and phosphate) necessary for remineralization. Moreover, saliva contains antibacterial components such as lysozyme, lactoferrin, and secretory IgA.

Any reduction in salivary flow (xerostomia), whether due to medication, systemic disease (e.g., Sjögren's syndrome), or radiation therapy, significantly increases the risk of caries. In clinical practice, patients with hyposalivation require specific management strategies, including saliva substitutes, increased fluoride exposure, and more frequent professional care.

Accurate early detection of caries has become more sophisticated, enabling dentists to intervene before cavitation occurs. Technologies such as quantitative light-induced fluorescence (QLF), laser fluorescence (DIAGNOdent), and optical coherence tomography (OCT) allow for real-time, non-invasive diagnosis of early demineralization.

These methods improve diagnostic accuracy, reduce false positives, and enable monitoring of lesion progression or arrest over time. They also support patient education by visualizing the problem before symptoms appear, leading to better compliance with preventive recommendations [5].

Caries is not merely a biological disease; it is deeply influenced by socioeconomic status (SES), education, cultural norms, and access to dental care. Low-income populations tend to have higher rates of untreated caries due to limited access to preventive services, lower health literacy, and diets high in fermentable carbohydrates.

Behavioral interventions such as motivational interviewing, school-based prevention programs, and mobile dental clinics have shown effectiveness in improving oral health in underserved communities. Public health policies that address the broader determinants of health, such as sugar taxation and fluoridated water, are crucial to reducing disparities in caries prevalence.

International health organizations, including the World Health Organization (WHO) and the FDI World Dental Federation, have called for integrated caries management that combines professional care, patient self-care, and community-wide initiatives.

Key strategies include:

- Incorporating oral health into primary healthcare systems
- Promoting sugar intake reduction through food industry regulation
- Scaling up preventive care in schools
- Supporting interdisciplinary education among healthcare providers
- Such holistic frameworks recognize that caries prevention must occur at multiple levels—biological, behavioral, and societal—to achieve long-lasting results.

Although environmental and behavioral factors are key drivers of dental caries, emerging research emphasizes the role of genetic predisposition in determining individual susceptibility. Studies have shown that genetic variations in enamel formation genes (AMELX, ENAM), salivary composition, taste preference genes (TAS2R38), and immune response genes (DEFB1, IL1B) can significantly influence caries risk.

For example, individuals with thinner enamel due to genetic factors may be more prone to demineralization even under moderate acid exposure. Similarly, variations in bitter taste receptors may affect dietary choices, particularly sugar intake, indirectly increasing caries prevalence. This genetic insight opens the door for personalized dental care, where preventive strategies and treatment plans are tailored based on an individual's biological risk profile.

Furthermore, epigenetic modifications—heritable changes in gene expression without altering DNA sequence—have been linked to long-term effects of early-life nutrition and microbial exposure. These can influence how the immune system and oral tissues respond to cariogenic stressors throughout life.

The psychosocial context in which dental care occurs can significantly impact treatment success and prevention outcomes. Fear of dental procedures, often rooted in childhood experiences, may lead to dental avoidance behavior, delaying necessary

treatment and increasing lesion severity. In pediatric and geriatric populations, this fear can be exacerbated by communication barriers or cognitive impairment.

To counter this, behavioral dentistry now incorporates cognitive-behavioral therapy (CBT) techniques, anxiety-reducing environments, and patient education to foster trust and compliance. Effective communication, especially in preventive counseling, is now recognized as essential in modifying patient habits related to oral hygiene and sugar consumption.

In schools and community programs, the involvement of caregivers, educators, and even peer networks has been shown to enhance the success of caries-prevention initiatives. Social reinforcement and collective health responsibility play crucial roles in embedding oral hygiene as a routine practice.

Emerging studies have highlighted the bi-directional relationship between oral and systemic health, particularly in the context of early childhood caries (ECC) and non-communicable diseases (NCDs) such as obesity, diabetes, and cardiovascular conditions.

CONCLUSION

Dental caries is a preventable yet persistently widespread disease with multifactorial origins and significant economic and health implications. Understanding the pathogenesis of caries enables clinicians and researchers to develop more effective treatments and prevention strategies. Modern management of caries emphasizes minimal intervention, patient-specific care, and a shift atoward bioactive, preventive, and sustainable approaches. Coordinated efforts between dental professionals, educators, public health authorities, and patients are essential to control the global burden of dental caries and improve overall oral health outcomes.

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