

Plaque Formation and Microbial Interactions: Insights into Oral Health and Disease

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Abstract—Background: Dental plaque is a complex biofilm that forms on tooth surfaces, comprising various microorganisms that interact with each other and the host. The oral microbiota is a diverse ecosystem that plays a crucial role in maintaining oral health, but dysbiosis can contribute to various oral diseases, including dental caries, periodontitis, and halitosis

Aims and objectives: To provide an in-depth analysis of the current understanding of the formation of dental plaque and the interactions between oral microorganisms, with the objectives of Understanding the process of plaque formation and exploring the role of microbial interactions in oral health and disease.

Methods: An electronic search on PubMed, Google scholar, Scopus for bibliographic and available literature was done using different databases by following key words.

Result: A comprehensive review revealed that dental plaque formation is a complex process involving the adherence of microorganisms to tooth surfaces, followed by the accumulation of additional microorganisms and the formation of a biofilm. Our findings highlight the importance of microbial interactions in maintaining oral homeostasis, and demonstrate that dysbiosis of the oral microbiota contributes to the development of oral diseases, including dental caries and periodontitis.

Conclusion: This study conclusive provides new insights into the formation of dental plaque and the interactions between oral microorganisms. Our findings emphasize the importance of maintaining a healthy oral microbiota and highlight the need for further research into the prevention and treatment of oral diseases.

Index Terms—Dental plaque, oral microbiota, microbial interactions, oral health, oral disease.

I. INTRODUCTION

The oral cavity is similar to other body sites in having a normal microbial flora that is complex and consists of a large number of microorganisms. Antoine van Leeuwenhoek, who was also an amateur scientist, observed under microscope minute creatures of different shapes and sizes in his tooth scrapings and water.¹

Dental plaque, a complex microbial biofilm that forms on tooth surfaces, plays a central role in both the maintenance of oral health and the development of oral diseases such as dental caries and periodontal disease. The dynamic process of plaque formation involves the adhesion of bacteria to the tooth surface and the subsequent growth and maturation of a bacterial community.²

II. FORMATION OF DENTAL PLAQUE

Dental plaque is a sticky, colourless film of bacteria that constantly forms on your teeth. It's primarily composed of bacteria, food particles, saliva, and other substances. The process of plaque formation is a step-by-step accumulation that occurs over time. Dental plaque formation starts immediately after tooth

brushing. Proteins derived from the saliva start depositing on the tooth surface in the form of a thin layer known as pellicle, thus, pellicle formation is the first step in dental plaque formation, here's how it forms:

Step 1: Pellicle Formation

A thin layer of salivary proteins, glycoproteins, and other molecules forms on the tooth surface. This layer is called the acquired pellicle.

Step 2: Microbial Adhesion

Bacteria from the oral cavity, such as Streptococci and Actinomyces, adhere to the acquired pellicle. This adhesion is facilitated by the presence of receptors on the bacterial surface and ligands on the pellicle. as the plaque matures, gram positive organisms are replaced by gram negative and anaerobic organisms.

Step 3: Biofilm Formation

The adherent bacteria multiply and form a biofilm, which is a complex community of microorganisms. The biofilm is held together by a matrix of extracellular polymeric substances (EPS), such as polysaccharides and proteins.

Step 4: Maturation of the Biofilm

The biofilm continues to grow and mature, with the formation of a complex community of microorganisms. The biofilm becomes more resistant to removal and more difficult to penetrate with antimicrobial agents.

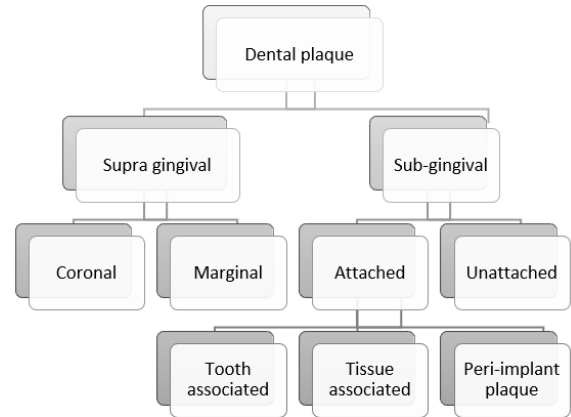
Step 5: Plaque Accumulation

The biofilm continues to accumulate on the tooth surface, forming a visible plaque. The plaque can be removed by regular brushing and flossing, but if left untreated, it can lead to the development of oral diseases such as dental caries and periodontitis.³

III. CLASSIFICATION OF DENTAL PLAQUE

The classification of dental plaque helps to distinguish between the different types based on various factors, including its location, composition, and the specific microorganisms present. Over time, plaque can develop into more harmful forms, leading to calculus (tartar) build-up, which can only be removed by professional cleaning. Dental plaque is commonly categorized into two main types: supragingival plaque, which forms above the gum line, and sub gingival plaque, which develops below the gum line. Each type of plaque presents unique challenges and requires

targeted intervention. Understanding the classification of dental plaque enables dental professionals to provide better personalized treatment options, improve patient oral hygiene practices, and reduce the risk of future dental complications. The study of plaque composition and its role in oral health continues to evolve, offering new insights into prevention and treatment methods.^{4,5,6} Depending on the site of formation, dental plaque can be classified as follows



IV. MICROBIAL SYNERGIES IN PLAQUE FORMATION

Dental plaque formation is a dynamic process primarily driven by microbial interactions.⁷ These interactions involve a complex community of microorganisms, including bacteria, fungi, viruses, and archaea, which thrive on the surfaces of teeth. ⁸Understanding the microbial dynamics in plaque formation is essential for comprehending the pathogenesis of various dental diseases, such as dental caries (cavities) and periodontal disease (gum disease).

Symbiosis: Some microbes in plaque engage in symbiotic relationships, where they cooperate for mutual benefit. For example, Streptococcus mutans produces acids as a byproduct of fermenting sugars, which lowers the pH of the surrounding environment. This acidic environment, in turn, favors the growth of acid-tolerant bacteria, such as Lactobacillus species, which further contribute to tooth enamel demineralization.

Antagonism: Some bacteria in plaque produce antimicrobial compounds that inhibit the growth of competing species. ⁸For instance, Streptococcus species can produce hydrogen peroxide, which inhibits the growth of harmful bacteria such as Porphyromonas

gingivalis. However, this antagonistic relationship can be disrupted by factors like poor oral hygiene or a diet high in sugars.⁹

Quorum Sensing: Microbes in plaque use a process called quorum sensing to communicate with one another. Through the production of signalling molecules, bacteria can coordinate their behaviour and form more organized biofilms.^{4,10} This communication is essential for the maturation of plaque and the establishment of microbial communities that can withstand environmental stresses.¹⁰

Pathogenicity: As plaque matures, pathogenic microorganisms may take over, leading to disease. Bacteria like *Porphyromonas gingivalis* and *Aggregatibacter actinomycetemcomitans* can cause inflammation of the gums and destruction of the supporting structures of the teeth, leading to periodontal disease. Additionally, acid-producing bacteria in plaque can lead to the demineralization of tooth enamel, contributing to the formation of cavities.^{11,12}

The formation of dental plaque is a result of intricate microbial interactions that evolve over time. Early colonizers pave the way for more bacteria to attach, and as plaque matures, the microbial community becomes more complex. These microbial communities are in constant interplay through mechanisms such as cooperation, competition, and communication, which can ultimately influence oral health. A balance in the microbial ecosystem of the plaque is crucial for maintaining oral health, whereas a disrupted balance can lead to dental diseases. Understanding these interactions provides insights into preventing and managing oral conditions through better oral hygiene practices and targeted therapies.

V. BACTERIAL COMPOSITION OF DENTAL PLAQUE: GRAM-POSITIVE VS. GRAM-NEGATIVE SPECIES

Gram-Positive and Gram-Negative Bacteria in Dental Plaque

Dental plaque is a complex microbial biofilm that contains a diverse range of bacteria, including both gram-positive and gram-negative species.^{4,13} The classification of bacteria into gram-positive and gram-negative categories is based on differences in their cell wall structure, which can influence their behavior and role in plaque formation and oral diseases.

A. Gram-Positive Bacteria in Dental Plaque

Gram-positive bacteria have a thick peptidoglycan layer in their cell walls, which stains purple when subjected to Gram staining. These bacteria are typically the early colonizers in plaque formation and play a critical role in the initial stages of biofilm development. Some key gram-positive bacteria in dental plaque include:

1. **Streptococcus Species**
 - *Streptococcus mutans*: Known for its role in the initiation of dental caries (tooth decay). It produces acids from the fermentation of sugars, leading to enamel demineralization.
 - *Streptococcus sanguinis*: A major early colonizer that competes with pathogenic bacteria, helping to maintain a healthy oral microbiota.
 - *Streptococcus oralis*: Part of the normal oral flora, playing a role in the initial attachment to the tooth surface.^{13,14}
2. **Actinomyces Species**
 - *Actinomyces viscosus* and *Actinomyces naeslundii* are commonly found in plaque and are involved in the initial attachment to the tooth surface. They are important for the formation of the biofilm matrix.
3. **Lactobacillus Species**
 - *Lactobacillus* species are involved in the fermentation of sugars and contribute to the acidification of the environment, potentially leading to enamel decay if their population becomes too large.
4. **Enterococcus Species**
 - *Enterococcus faecalis* is often found in the later stages of plaque formation and is associated with periodontal diseases.

B. Gram-Negative Bacteria in Dental Plaque

Gram-negative bacteria have a thinner peptidoglycan layer and an outer membrane, which makes them more resistant to antibiotics and immune responses. These bacteria tend to appear in the later stages of plaque development and are often implicated in periodontal disease due to their ability to produce inflammatory substances. Key gram-negative bacteria in dental plaque include:

1. ***Porphyromonas gingivalis***
 - *P. gingivalis* is one of the most well-known periodontal pathogens. It is associated with the development of periodontitis and can evade the

immune system through mechanisms like immune suppression and tissue invasion.

2. *Fusobacterium nucleatum*
 - *F. nucleatum* acts as a bridge between early colonizers (such as *Streptococcus* species) and late-stage pathogens. It plays a role in the development of both periodontal disease and inflammatory conditions.⁴
3. *Treponema denticola*
 - A spirochete associated with advanced periodontal disease, *T. denticola* is highly mobile and can invade tissue, contributing to tissue destruction in periodontitis.
4. *Aggregatibacter actinomycetemcomitans*
 - This bacterium is highly virulent and is often found in the periodontal pockets of individuals with aggressive periodontitis. It is capable of producing toxins that contribute to periodontal tissue destruction.
5. *Prevotella intermedia*
 - *P. intermedia* is often found in the subgingival biofilm and has been associated with both gingivitis and periodontitis. It can produce endotoxins and inflammatory mediators that exacerbate gum inflammation.

VI. ROLE OF GRAM-POSITIVE AND GRAM-NEGATIVE BACTERIA IN PLAQUE FORMATION AND ORAL HEALTH

1. Early Colonization by Gram-Positive Bacteria
 - Gram-positive bacteria, such as *Streptococcus* and *Actinomyces*, are the first to colonize the tooth surface after pellicle formation. These bacteria are well-adapted to adhere to the enamel and are critical in the initial stages of plaque buildup.
2. Transition to Gram-Negative Bacteria
 - As plaque matures and becomes more anaerobic in nature, gram-negative bacteria begin to dominate. These bacteria, such as *Porphyromonas gingivalis* and *Fusobacterium nucleatum*, thrive in the deeper layers of plaque, where oxygen levels are lower. Their presence is associated with the progression from gingivitis to more severe periodontal diseases.
3. Acid Production and Enamel Demineralization
 - Gram-positive bacteria, particularly *Streptococcus mutans* and *Lactobacillus* species, contribute to the production of acids from carbohydrate

fermentation. This acid production leads to the demineralization of tooth enamel, a key factor in the development of dental caries.

4. Inflammation and Tissue Destruction
 - Gram-negative bacteria are often implicated in the inflammation seen in periodontal diseases. For example, *P. gingivalis* produces various virulence factors, including proteases and endotoxins, that stimulate the immune system and contribute to tissue breakdown.^{9,10}

Both gram-positive and gram-negative bacteria play essential roles in the formation and maturation of dental plaque. Gram-positive bacteria are crucial for initial plaque colonization, while gram-negative bacteria become more prominent as plaque matures, contributing to the development of oral diseases like gingivitis and periodontitis. The balance between these bacterial groups and their interactions within the plaque biofilm is key to maintaining oral health. Effective oral hygiene practices are necessary to manage the bacterial composition of dental plaque and prevent the onset of oral diseases.

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