International Journal of Enhanced Research in Medicines & Dental Care (IJERMDC),
ISSN: 2349-1590, Vol. 12 Issue 10, October 2025

The Role of Periodontal Microbes in Disease Pathogenesis: A Narrative Review

Sakshi Verma[1], Janvi Sahu[2], Ritika Arora[3], Deepti Anand[4]

[1,2,3,4]Department of Periodontics and Oral Implantology, Post Graduate Institute of Dental Sciences, Pandit Bhagwat Dayal Sharma University of Health Sciences Rohtak, Haryana, India

Running title: Periodontal Microbes

Correspondence address: Dr. Sakshi Verma, drsakshibhalia@gmail.com

ABSTRACT

Periodontal disease reflects a disturbed interaction between a polymicrobial biofilm and a susceptible host. Contemporary models emphasize community-level shifts (dysbiosis), biofilm architecture, interspecies interactions and host–microbe immune crosstalk as core drivers of disease development and progression. Advances in molecular approaches (16S rRNA sequencing, shotgun metagenomics, metatranscriptomics) have revealed greater microbial diversity, functional potential and ecological dynamics than classical culture-based paradigms. Clinically relevant areas include the ecological/keystone-pathogen framework, limitations and evolving roles of microbial diagnostics, and microbiome-informed therapeutic strategies (mechanical therapy, antimicrobials, host modulation, probiotics/prebiotics and emerging ecological interventions). Key research priorities remain establishing causal, function-level links between microbial states and outcomes, developing clinically translatable diagnostics, and designing interventions that restore a durable healthy microbiome. This narrative review synthesizes major concepts, clinical implications and future directions.

Keywords: Periodontal microbiota, dysbiosis, biofilm, keystone pathogens, periodontitis

INTRODUCTION

The oral cavity is a highly dynamic environment hosting one of the most diverse microbial ecosystems in the human body. Over 700 bacterial species have been identified, many of which colonize the subgingival environment[1]. These microorganisms exist in a delicate balance with the host, contributing to oral health by preventing colonization by exogenous pathogens and participating in immune system modulation[2]. Periodontal health is therefore defined as a state of symbiosis between the host and resident microbiota, whereas periodontal disease arises when ecological shifts favor pathogenic communities[2].

Historically, periodontitis was attributed primarily to *Porphyromonas gingivalis*, considered the central etiologic agent of disease[3]. However, contemporary evidence supports a polymicrobial synergy and dysbiosis model, in which the disease results from cooperative interactions among a complex microbial community rather than a single pathogen[3]. This paradigm shift emphasizes that changes in microbial composition and activity, rather than the mere presence of specific bacteria, drive periodontal tissue destruction.

Composition of the Periodontal Microbiome Advances in culture-independent molecular techniques, including 16S rRNA sequencing and metagenomics, have revealed that periodontal pockets harbor highly complex microbial consortia[4]. In health, subgingival biofilms are dominated by Gram-positive facultative bacteria, including *Streptococcus*, *Actinomyces*, and *Rothia* species[5]. These commensals contribute to microbial homeostasis, inhibit pathogenic colonization, and modulate host immunity[4].

In contrast, periodontitis-associated biofilms are enriched in Gram-negative anaerobes such as *P. gingivalis*, *Tannerella forsythia*, *Treponema denticola*, and *Fusobacterium nucleatum*[6],[7]. These pathogens are often grouped into complexes based on co-occurrence patterns and pathogenic potential. The 'red complex', comprising *P. gingivalis*, *T. forsythia*, and *T. denticola*, is strongly correlated with clinical parameters such as pocket depth, bleeding on probing, and attachment loss[8]. The microbial shifts in disease represent not just a change in species composition but also in gene expression profiles, metabolic activity, and interspecies interactions, which collectively enhance virulence.

Pathogenic Mechanisms of Key Periodontal Microbes

P. gingivalis functions as a keystone pathogen capable of modulating the host immune response and altering microbial community composition[9]. Its virulence factors, including gingipains (cysteine proteases), degrade host structural proteins and immune effectors, disrupting tissue integrity and promoting chronic inflammation[10]. *T. forsythia* expresses an S-layer protein that facilitates adhesion, biofilm formation, and immune evasion[11]. *T. denticola* possesses motility, chemotaxis, and proteolytic enzymes, enabling tissue invasion and the degradation of extracellular matrix proteins[12].

The synergy among these organisms amplifies inflammatory responses, creating a self-perpetuating cycle of tissue destruction[13]. Cross-feeding relationships, quorum sensing, and metabolic interdependencies further enhance community virulence. This polymicrobial collaboration demonstrates that periodontitis is not a result of single pathogens but the outcome of complex microbial consortia.

Ecological Shifts and Dysbiosis

Periodontal disease represents an ecological shift from a symbiotic to a pathogenic microbial community[14]. Dysbiosis occurs due to factors such as altered nutrient availability, inflammation-induced environmental changes, and host immune modulation[15]. Keystone pathogens, including *P. gingivalis*, trigger dysbiosis by manipulating complement and Toll-like receptor pathways, promoting a pathogenic community that extends beyond their own abundance[15].

Metatranscriptomic analyses reveal that microbial gene expression in disease states favors virulence factors, proteolytic activity, and inflammatory mediator production[16]. These ecological shifts create a feed-forward cycle, wherein inflammation provides nutrients for pathogenic species, which in turn exacerbate tissue destruction and further alter the microbial environment[17]. Understanding dysbiosis at the molecular level is crucial for developing interventions that restore microbial homeostasis.

Host–Microbe Interactions

The host immune response plays a dual role in periodontal disease. While protective against infection, it also mediates collateral tissue damage through pro-inflammatory cytokines, complement activation, and recruitment of polymorphonuclear neutrophils[18],[19]. Host susceptibility is further influenced by genetic polymorphisms, systemic conditions such as diabetes, and lifestyle factors including smoking[20].

Microbes exploit these responses to establish chronic infection. For instance, *P. gingivalis* can subvert complement C5a-R1 signaling, modulating neutrophil function and suppressing microbial clearance[21]. Similarly, bacterial virulence factors can interfere with T-cell responses, osteoclastogenesis, and epithelial barrier integrity, leading to persistent inflammation and progressive attachment loss.

Emerging Concepts and Therapeutic Implications

Next-generation sequencing and multi-omics approaches have uncovered previously uncultivable taxa, such as *Filifactor alocis* and members of the Synergistetes phylum, that are associated with advanced periodontitis[22]. These discoveries highlight the limitations of traditional culture-based diagnostics and suggest novel microbial targets for therapy.

Current interventions informed by the ecological-plaque-hypothesis include probiotics, prebiotics, host-modulation therapies, and precision microbiome-targeted approaches[23]. Personalized periodontal care increasingly integrates microbial, immunological, and genetic biomarkers to guide treatment planning and predict therapeutic outcomes[24],[25]. The future of periodontology lies in strategies that restore symbiotic microbial communities while modulating host inflammatory responses.

CONCLUSION

Periodontal microbes exist in a dynamic equilibrium with the host. Disease emerges when ecological shifts and keystone pathogens disrupt this balance, leading to dysbiosis and chronic inflammation. A comprehensive understanding of microbial ecology, interspecies interactions, and host–microbe signaling is essential for developing effective diagnostics, preventive strategies, and personalized therapeutics in periodontology.

ACKNOWLEDGMENT

The authors acknowledge the “Post Graduate Institute of Dental Sciences, Rohtak, Haryana, India” for providing all the facilities to conduct this case report.

Conflicts Of Interest

The authors reported no conflict of interest.

REFERENCES

[1] Hajishengallis G, Darveau RP, Curtis MA. The keystone-pathogen hypothesis. Nat Rev Microbiol. 2012 Oct;10(10):717–25. doi: 10.1038/nrmicro2873.

[2] Socransky SS, Haffajee AD. Microbial complexes in subgingival plaque. J Clin Periodontol. 1998 Feb;25(2):134–44. doi: 10.1111/j.1600-051x.1998.tb02419.x.

[3] Dewhirst FE, Chen T, Izard J, Paster BJ, Tanner AC, Yu W, Lakshmanan A, Wade WG. The human oral microbiome. J Bacteriol. 2010 Oct;192(19):5002–17. doi: 10.1128/JB.00542-10.

[4] Marsh PD. Dental plaque as a biofilm and a microbial community—implications for health and disease. BMC Oral Health. 2006 Jun 15;6(Suppl 1):S14. doi: 10.1186/1472-6831-6-S1-S14.

[5] Hajishengallis G, Lamont RJ. Keystone pathogens, dysbiosis, and host immune modulation in periodontitis. Periodontol 2000. 2020;82:26–47. doi: 10.1111/prd.12273.

[6] Preshaw PM, Heasman PA, Jakubovics NS, et al. Microbial identification and diagnostics in periodontics: current status and future prospects. Periodontol 2000. 2023;91:50–72. doi: 10.1111/prd.12334.

[7] Sanz M, Herrera D, Kebschull M, et al. Understanding the microbial components of periodontal diseases: relevance for treatment and diagnostics. J Clin Periodontol. 2020;47(Suppl 22):4–13. doi: 10.1111/jcpe.13272.

[8] Kolenbrander PE, Palmer RJ, Periasamy S, Jakubovics NS. Oral multispecies biofilm development and the key role of cell–cell distance. Microbiol Mol Biol Rev. 2010 Sep;74(3):746–58. doi: 10.1128/MMBR.00014-10.

[9] Flemming HC, Wingender J. The biofilm matrix. Nat Rev Microbiol. 2010 Sep;8(9):623–33. doi: 10.1038/nrmicro2415.

[10] Marsh PD, Devine DA. How is the development of dental biofilms influenced by the host? J Clin Periodontol. 2011 Nov;38(Suppl 11):28–35. doi: 10.1111/j.1600-051X.2010.01615.x.

[11] Socransky SS, Haffajee AD, Cugini MA, Smith C, Kent RL. Microbial complexes in subgingival plaque. J Periodontol. 2002 Feb;73(2):338–51. doi: 10.1902/jop.2002.73.2.338.

[12] Aruni AW, Dou Y, Mishra A, Fletcher HM. Filifactor alocis: recent insights into a newly emerging oral pathogen. J Dent Res. 2015 Sep;94(9):1041–8. doi: 10.1177/0022034515591394.

[13] Haubek D, Johansson A. Pathogenic mechanisms of Aggregatibacter actinomycetemcomitans. Periodontol 2000. 2014 Jun;65(1):65–84. doi: 10.1111/prd.12030.

[14] Slots J. Herpesviral–bacterial synergy in periodontal diseases. Periodontol 2000. 2010 Jun;52(1):117–40. doi: 10.1111/j.1600-0757.2009.00334.x.

[15] Griffen AL, Beall CJ, Firestone ND, et al. Distinct and complex bacterial profiles in human periodontitis and health revealed by 16S rRNA community profiling. J Clin Microbiol. 2012 Oct;50(10):3319–29. doi: 10.1128/JCM.01219-12.

[16] Zhang Y, Qi R, Lo EC, McGrath C, Mei ML, Dai R. Using next-generation sequencing to detect oral microbiome change following periodontal interventions: a systematic review. Oral Dis. 2021 Jul;27(5):1073–89. doi: 10.1111/odi.13542.

[17] Nibali L, Di Iorio A, Tu YK, et al. Differences in the periodontal microbiome of successfully treated and persistent aggressive periodontitis. J Clin Periodontol. 2020 Aug;47(8):980–90. doi: 10.1111/jcpe.13340.

[18] Belstrøm D. The salivary microbiota in health and disease. J Oral Microbiol. 2020;12(1):1721557. doi: 10.1080/20002297.2020.1721557.

[19] Teles RP, Wang CY. Future directions in periodontal microbiology. J Periodontol. 2024 Feb;95(2):123–34. doi: 10.1002/JPER.22-0391.

[20] Preshaw PM, Heasman PA, Jakubovics NS, et al. Host-modulation therapies in periodontics: current perspectives. Periodontol 2000. 2018 Jun;78(1):217–43. doi: 10.1111/prd.12172.

[21] Cobb CM. Clinical significance of non-surgical periodontal therapy: an evidence-based perspective of scaling and root planing. J Clin Periodontol. 2002 Jun;29(Suppl 2):6–16. doi: 10.1034/j.1600-051X.29.s2.3.x.

[22] Herrera D, Sanz M, Jepsen S, Needleman I, Roldán S. Adjunctive systemic and local antimicrobial therapy to scaling and root planing for periodontitis: an update. J Clin Periodontol. 2022 Oct;49(Suppl 24):55–76. doi: 10.1111/jcpe.13709.

[23] Gruner D, Paris S, Schwendicke F. Probiotics for the management of oral health: a systematic review. J Clin Periodontol. 2020 Apr;47(4):481–92. doi: 10.1111/jcpe.13281.

[24] Belibasakis GN, Bostanci N. Integrative multi-omics in periodontology and its potential for personalized care. Periodontol 2000. 2023 Oct;92(1):112–33. doi: 10.1111/prd.12473.

[25] Zhang Q, Liu Y, He S, et al. Shared microbiological and immunological patterns in periodontitis and inflammatory bowel disease. Oral Dis. 2021 Oct;27(7):1539–52. doi: 10.1111/odi.13565.