Open Access Journal of Surgery
ISSN: 2476-1346

Research Article
Volume 16 Issue 2 - January 2025
DOI: 10.19080/OAJS.2025.16.555935

Open Access J Surg

Oral Microbiome Engineering: A Frontier in Dental Disease Prevention and Personalized Oral Care

Ashish Pandey*, Gunjan Tomar, Nidhi Kumari, Pradnya Ubale and Shrey Jain

Daswani Dental College affiliated to Rajasthan University of Health Sciences, Jaipur, Rajasthan, India

Received: January 06, 2025; **Published:** January 22, 2025

***Corresponding author**: Ashish Pandey, Daswani Dental College affiliated to Rajasthan University of Health Sciences, Jaipur, Rajasthan, India.

Abstract

The oral microbiome, a dynamic and complex ecosystem of microorganisms residing in the oral cavity, plays a crucial role in oral health and disease. Recent advancements in microbiome research have paved the way for novel therapeutic strategies, particularly oral microbiome engineering, which holds immense potential for the prevention and management of dental diseases. This approach aims to manipulate the microbial composition within the oral cavity to restore a balanced ecosystem, thereby preventing dysbiosis and reducing the risk of conditions such as dental caries, periodontal disease, and oral infections. Key strategies include the use of probiotics, prebiotics, antimicrobial peptides, and advanced technologies like CRISPR-Cas systems, which have shown promising results in modulating the microbiome to favor health-promoting bacteria.

Oral microbiome engineering also promises to enable personalized oral care by leveraging advancements in genomic sequencing, bioinformatics, and microbiome profiling, allowing for tailored treatment plans that align with the individual's unique microbiome composition. However, the implementation of these innovations faces significant challenges, including the complexity of the oral microbiome, safety concerns, ethical considerations, and regulatory barriers. Despite these hurdles, the potential of oral microbiome engineering to revolutionize dental care is clear, offering a shift from traditional disease treatment to proactive prevention and personalized medicine. This review explores the composition and function of the oral microbiome, the concept of dysbiosis, the latest advancements in microbiome engineering, and the future directions for this cutting-edge field in oral health. By addressing current challenges and understanding the intricate relationship between the microbiome and oral health, the integration of microbiome-based therapies into clinical practice could significantly improve outcomes for dental patients globally.

Key words: Oral Microbiome; Microbiome Engineering; Dysbiosis; Dental Diseases; Personalized Oral Care; Probiotics; CRISPR-Cas; Antimicrobial Peptides

Abbreviations: AMPs: Antimicrobial Peptides; OMT: Oral Microbiota Transplants

Introduction

The human oral cavity harbours one of the most diverse microbial ecosystems, with over 700 bacterial species identified [1]. These microorganisms form biofilms on oral surfaces and establish a symbiotic relationship with the host. A balanced oral microbiome is critical for preventing colonization by pathogens, modulating the immune response, and maintaining oral homeostasis [2]. However, factors such as poor hygiene, dietary habits, systemic diseases, and medications can disrupt this balance, leading to dysbiosis and oral pathologies. This article explores emerging strategies in oral microbiome engineering to prevent and treat dental diseases while enabling personalized oral healthcare solutions.

Composition and Function of the Oral Microbiome

The oral microbiome includes bacteria, viruses, fungi, archaea, and protozoa, with bacteria being the most dominant group. Key microbial communities include:

Streptococcus spp

These are primary colonizers that contribute to the formation of dental plaque [3].

Actinomyces spp

They participate in biofilm maturation and provide structural support to plaque communities [4].

Fusobacterium nucleatum

Acts as a bridge organism, connecting early and late colonizers [5].

The oral microbiome supports health by

Producing antimicrobial compounds

Beneficial bacteria produce bacteriocins and hydrogen peroxide, inhibiting pathogenic growth [6].

Maintaining Oral pH

Microbial metabolism of nitrate to nitrite aids in pH regulation, protecting enamel [7].

Modulating the immune system

Commensal microbes interact with mucosal immune cells, enhancing tolerance and defense mechanisms [8].

Emerging studies highlight the oral microbiome's role beyond oral health, linking it to cardiovascular diseases, diabetes, and Alzheimer's disease [9,10].

Microbial Dysbiosis and Dental Diseases

Dysbiosis, an imbalance in microbial communities, has been implicated in several dental conditions:

Dental caries

Acidogenic bacteria, such as Streptococcus mutans and Lactobacillus spp., produce lactic acid, leading to enamel demineralization [11].

Periodontitis

Dysbiosis in subgingival biofilms, dominated by Porphyromonas gingivalis, Tannerella forsythia, and Treponema denticola, triggers chronic inflammation and tissue destruction [12].

Oral Candidiasis

Overgrowth of Candida albicans in immunocompromised individuals leads to fungal infections [13].

Understanding the mechanisms underlying dysbiosis is pivotal for developing targeted therapeutic interventions.

Advancements in Oral Microbiome Engineering

Probiotics and prebiotics

Probiotics such as Lactobacillus reuteri and Bifidobacterium spp. are introduced to restore microbial balance, while prebiotics like inulin promote beneficial bacterial growth [14,15]. Recent trials demonstrated the efficacy of Lactobacillus reuteri in reducing periodontal inflammation [16].

Antimicrobial Peptides (AMPs)

AMPs, such as defensins and histatins, selectively target pathogenic bacteria. Synthetic AMPs like Pexiganan have shown promise in biofilm disruption [17,18].

CRISPR-Cas systems

CRISPR-based gene editing enables precise targeting of virulence factors in pathogens like S. mutans. A recent study highlighted CRISPR's potential to inhibit biofilm formation by disrupting quorum sensing pathways [19].

Microbiota transplants

Oral microbiota transplants (OMT) are emerging as a novel approach to restore microbial diversity. A pilot study reported successful recolonization of beneficial bacteria in patients with refractory periodontitis [20].

Precision prebiotic engineering

Custom-designed prebiotics targeting specific microbial pathways offer a tailored approach to modulating the oral microbiome [21].

Personalized Oral Healthcare

Advances in sequencing technologies, such as 16S rRNA and metagenomics, allow detailed microbiome profiling. Personalized interventions based on an individual's microbial and genetic makeup are now possible [22]. For instance:

Risk Prediction: Microbiome analysis can predict susceptibility to caries or periodontitis, enabling early preventive measures [23]. Targeted Therapeutics: Formulating probiotic strains tailored to an individual's oral microbiota enhances treatment outcomes [24].

Challenges and Future Directions

Despite its promise, oral microbiome engineering faces challenges:

Microbial Complexity: Interactions within the microbiome and with the host are not fully understood [25]. Safety Concerns: Manipulating microbial communities may have unintended systemic effects [26]. Regulatory Hurdles: The approval of microbiome-based therapies requires rigorous validation [27]. Future research should focus on understanding microbial ecology, refining engineering tools, and conducting large-scale clinical trials.

Conclusion

The advent of oral microbiome engineering marks a revolutionary shift in the prevention and treatment of dental diseases. By targeting the underlying microbial communities rather than symptomatic manifestations, these novel approaches promise to improve outcomes in conditions like caries, periodontitis, and oral infections. Probiotics, prebiotics, antimicrobial peptides, and CRISPR-Cas systems exemplify the potential of these tools in restoring microbial balance and

How to cite this article: Ashish P, Gunjan T, Nidhi K, Pradnya U, Shrey J. Oral Microbiome Engineering: A Frontier in Dental Disease Prevention and Personalized Oral Care. Open Access J Surg. 2025; 16(2): 555935. DOI: 10.19080/OAJS.2025.16.555935

enhancing oral health. Furthermore, personalized oral healthcare, underpinned by advances in sequencing technologies and bioinformatics, paves the way for tailored treatments and risk predictions based on individual microbiome profiles.

However, the journey of integrating oral microbiome engineering into clinical practice remains challenging. The complexity of microbial ecosystems, safety concerns associated with genetic engineering, and regulatory barriers underscore the need for rigorous research and collaborative efforts. It is imperative to address these challenges through multidisciplinary approaches that combine dentistry, microbiology, and computational biology. Additionally, ethical considerations must guide the development and deployment of microbiome-based therapies to ensure equitable access and patient safety. As research continues to unravel the intricacies of the oral microbiome, the potential for preventive and therapeutic breakthroughs becomes ever more tangible. The future of dentistry lies in embracing these innovations, fostering a paradigm shift from reactive treatment to proactive, personalized care, thereby enhancing the quality of life for patients worldwide.

References

1. Dewhirst FE, Chen T, Izard J, Paster BJ, Tanner ACR, et al. (2010) The human oral microbiome. J Bacteriol 192(19): 5002-5017.
2. Wade WG (2013) The oral microbiome in health and disease. Pharmacol Res 69(1): 137-143.
3. Kolenbrander PE (2010) Oral multispecies biofilm development. Trends Microbiol 18(9): 417-423.
4. Nyvad B (2013) Biofilm and microbial dynamics in dental caries. Eur J Oral Sci 121(2): 133-135.
5. Lamont RJ (2018) Role of Fusobacterium nucleatum in periodontal disease. Nat Rev Microbiol 16(10): 702-714.
6. Marsh PD (2006) Dental plaque as a biofilm and a microbial community-Implications for health and disease. BMC Oral Health 6(Suppl 1): S14.
7. Rosier BT (2018) Modulation of oral ecology by nitrate and nitrite. Front Cell Infect Microbiol 8: 47.
8. Belkaid Y, Hand TW (2014) Role of the microbiota in immunity and inflammation. Cell 157(1): 121-141.
9. Kitamoto S (2020) The oral microbiome and systemic health. Genome Med 12(1): 109.
10. Singhrao SK (2015) Oral microbiome and Alzheimer's disease. J Alzheimers Dis 44(3): 555-566.
11. Pitts NB (2017) Dental caries. Nat Rev Dis Primers 3: 17030.
12. Hajishengallis G (2014) Dysbiosis and its role in periodontal disease. Trends Immunol 35(12): 491-496.
13. Calderone RA, Fonzi WA (2001) Virulence factors of Candida albicans. Trends Microbiol 9(7): 327-335.
14. Laleman I (2019) Probiotics for oral health: A systematic review. J Clin Periodontol 46(Suppl 21): 62-82.
15. Gibson GR (2004) Prebiotics: Concept, definition, and methodology. Food Sci Technol Bull 1: 1-17.
16. Teughels W (2021) Probiotic bacteria for oral health. Periodontol 2000 85(1): 92-113.
17. Krishnan S (2021) Antimicrobial peptides: An oral microbiome-targeted therapy. Dent Res J (Isfahan) 18: 37.
18. Hirt H (1999) Selective antimicrobial activity of synthetic histidine-rich peptides. Antimicrob Agents Chemother 43(10): 2494-2500.
19. Bikard D (2014) Exploiting CRISPR-Cas systems for targeting and editing bacterial genomes. Curr Opin Microbiol 19: 114-119.
20. Koo H (2018) Targeting oral biofilms: State of the science. Int J Oral Sci 10(1): 28.
21. Arora A (2023) Precision prebiotics for oral health. Oral Dis 29(1): 12-19.
22. Belstrøm D (2020) The human oral microbiome-An overview of current knowledge. Oral Dis 26(Suppl 1): 139-147.
23. Tanner AC (2018) Microbiome profiling in dental caries. J Clin Microbiol 56(7): e00114-e00118.
24. McDonald D (2018) Personalized oral health strategies using microbiome data. PLoS Biol 16(3): e2006871.
25. Zaura E (2009) The complexity of oral microbiota. J Dent Res 88(11): 932-940.
26. Ghosh TS (2019) Safety and ethical challenges in microbiome therapy. Microb Cell 6(5): 178-182.
27. Turnbaugh PJ (2017) Policy and regulatory challenges in microbiome research. Science 358(6369): 756-760.

DOI: 10.19080/OAJS.2025.16.555935

How to cite this article: Ashish P, Gunjan T, Nidhi K, Pradnya U, Shrey J. Oral Microbiome Engineering: A Frontier in Dental Disease Prevention and Personalized Oral Care. Open Access J Surg. 2025; 16(2): 555935. DOI: 10.19080/OAJS.2025.16.555935