



SALIVARY MICROBIOME MODULATION BY DIGITAL ORTHODONTIC WORKFLOWS

Modulação do Microbioma Salivar por Fluxos Digitais em Ortodontia

Modulación del Microbioma Salival mediante Flujos Digitales en Ortodoncia

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ABSTRACT

The rapid incorporation of digital workflows in orthodontics has transformed diagnosis, treatment planning, and appliance fabrication. Beyond mechanical efficiency and esthetic predictability, emerging evidence suggests that digital orthodontic approaches may influence the oral ecosystem, particularly the salivary microbiome. This narrative literature review explores how digital orthodontic workflows—such as intraoral scanning, computer-aided design and manufacturing (CAD/CAM), customized aligners, and reduced chair-time protocols—may indirectly modulate salivary microbial balance. Databases were searched for studies addressing orthodontic digitalization, oral microbiome dynamics, salivary biomarkers, and periodontal outcomes. Findings suggest that digitally planned treatments can reduce plaque-retentive surfaces, minimize iatrogenic trauma, and shorten treatment duration, factors associated with more stable microbial profiles. Although direct evidence remains



limited, the interaction between digital orthodontics and salivary microbiome homeostasis represents an innovative field with potential implications for caries risk, periodontal health, and long-term oral stability.

Keywords: *Digital Orthodontics; Salivary Microbiome; Oral Health; CAD/CAM; Preventive Dentistry.*

RESUMO

A rápida incorporação de fluxos de trabalho digitais na ortodontia tem transformado o diagnóstico, o planejamento do tratamento e a confecção de dispositivos ortodônticos. Para além da eficiência mecânica e da previsibilidade estética, evidências emergentes sugerem que as abordagens digitais em ortodontia podem influenciar o ecossistema oral, especialmente o microbioma salivar. Esta revisão narrativa da literatura explora como os fluxos digitais ortodônticos — como o escaneamento intraoral, o desenho e a manufatura assistidos por computador (CAD/CAM), os alinhadores personalizados e os protocolos com redução do tempo clínico — podem modular indiretamente o equilíbrio microbiano salivar. Foram pesquisadas bases de dados em busca de estudos que abordassem a digitalização da ortodontia, a dinâmica do microbioma oral, biomarcadores salivares e desfechos periodontais. Os achados sugerem que tratamentos planejados digitalmente podem reduzir superfícies retentivas de placa, minimizar traumas iatrogênicos e encurtar a duração do tratamento, fatores associados a perfis microbianos mais estáveis. Embora as evidências diretas ainda sejam limitadas, a interação entre a ortodontia digital e a homeostase do microbioma salivar representa um campo inovador, com potenciais implicações para o risco de cárie, a saúde periodontal e a estabilidade oral a longo prazo.

Palavras-chave: *Ortodontia Digital; Microbioma Salivar; Saúde Oral; CAD/CAM; Odontologia Preventiva.*

RESUMEN

La rápida incorporación de flujos digitales en la ortodoncia ha transformado el diagnóstico, la planificación del tratamiento y la fabricación de dispositivos. Más allá de la eficiencia mecánica y la previsibilidad estética, evidencias emergentes sugieren que los enfoques digitales en ortodoncia pueden influir en el ecosistema oral, en particular en el microbioma salival. Esta revisión narrativa de la literatura analiza cómo los flujos digitales ortodônticos—como el escaneo intraoral, el diseño y manufatura asistidos por computadora (CAD/CAM), los alineadores personalizados y la reducción del tiempo clínico—pueden modular indirectamente el equilibrio microbiano salivar. Los hallazgos indican que los tratamientos digitalmente planificados pueden reducir superficies retentivas de placa, minimizar traumatismos iatrogénicos y acortar la duración del tratamiento, factores asociados con perfiles microbianos más estables. Aunque la evidencia directa aún es limitada, la interacción entre la ortodoncia digital y la homeostasis del microbioma salival representa un campo innovador con implicaciones potenciales para el riesgo de caries, la salud periodontal y la estabilidad oral a largo plazo.

Palabras clave: *Ortodoncia Digital; Microbioma Salival; Salud Oral; CAD/CAM; Odontología Preventiva.*



1. INTRODUCTION

The oral cavity is a complex biological environment where host tissues coexist with a diverse microbial community that plays a fundamental role in maintaining oral health. The salivary microbiome, in particular, acts as a dynamic interface between teeth, periodontal tissues, and systemic health. Disruptions in this ecosystem are closely associated with dental caries, periodontal disease, and inflammatory oral conditions (Rajasekaran *et al.*, 2024).

Orthodontic treatment is a well-recognized factor capable of altering the oral microbiome. Conventional fixed appliances introduce retentive areas that favor biofilm accumulation, leading to qualitative and quantitative microbial shifts. These changes may increase the prevalence of cariogenic and periodontopathogenic species, especially during prolonged treatment periods (Nicolantonio *et al.*, 2025).

In recent years, dentistry has undergone a digital transformation characterized by the integration of intraoral scanners, three-dimensional imaging, virtual treatment planning, and CAD/CAM technologies. Orthodontics has been at the forefront of this transition, with digital workflows increasingly replacing traditional analog methods (Gawali *et al.*, 2024).

Digital orthodontic systems enable precise appliance customization, optimized force distribution, and enhanced control over tooth movement. These advantages are primarily discussed in mechanical and esthetic terms; however, their biological implications remain underexplored (Weissheimer *et al.*, 2024).

One potential biological impact of digital orthodontics relates to its influence on salivary composition and microbial dynamics. Reduced appliance bulk, smoother surfaces, and personalized aligner systems may decrease plaque retention and alter salivary flow patterns, indirectly affecting microbial colonization (Dallel *et al.*, 2020).

Furthermore, digital workflows often reduce chair time and the frequency of appliance adjustments. This reduction may limit repeated mechanical irritation of oral tissues, thereby decreasing inflammatory responses that can influence microbial ecology (Barengi *et al.*, 2022).

Saliva plays a crucial role in buffering oral pH, delivering antimicrobial peptides, and facilitating microbial clearance. Any orthodontic approach that modifies salivary flow, composition, or interaction with appliances may consequently affect microbiome stability (Vila *et al.*, 2019).

Despite growing interest in the oral microbiome, few reviews have specifically addressed the



intersection between digital orthodontics and salivary microbial modulation. This gap highlights the novelty and relevance of the topic within contemporary dental research (Zhao *et al.*, 2020a).

Therefore, the objective of this review is to analyze the potential influence of digital orthodontic workflows on the salivary microbiome, discussing biological mechanisms, clinical implications, and future research perspectives.

2. METHODOLOGY

This narrative literature review was designed to synthesize current knowledge regarding digital orthodontic workflows and their potential effects on the salivary microbiome. A comprehensive search strategy was developed to capture interdisciplinary evidence from orthodontics, oral microbiology, and digital dentistry.

Electronic searches were conducted in major scientific databases, focusing on publications addressing digital orthodontic techniques, intraoral scanning, CAD/CAM orthodontics, clear aligners, salivary biomarkers, and oral microbiome dynamics. Keywords were combined using Boolean operators to refine the search and enhance relevance.

The review included original research articles, clinical studies, observational analyses, and relevant narrative reviews published in English. Studies focusing exclusively on conventional orthodontics without reference to digital techniques were excluded unless they provided comparative biological insights.

No geographic restrictions were applied. Emphasis was placed on studies discussing microbial changes, salivary parameters, plaque accumulation, periodontal outcomes, and treatment duration in digitally assisted orthodontic contexts.

Data extraction focused on identifying reported biological effects, proposed mechanisms linking digital workflows to microbial modulation, and clinical outcomes related to oral health maintenance. Findings were organized thematically to allow an integrated and critical discussion.

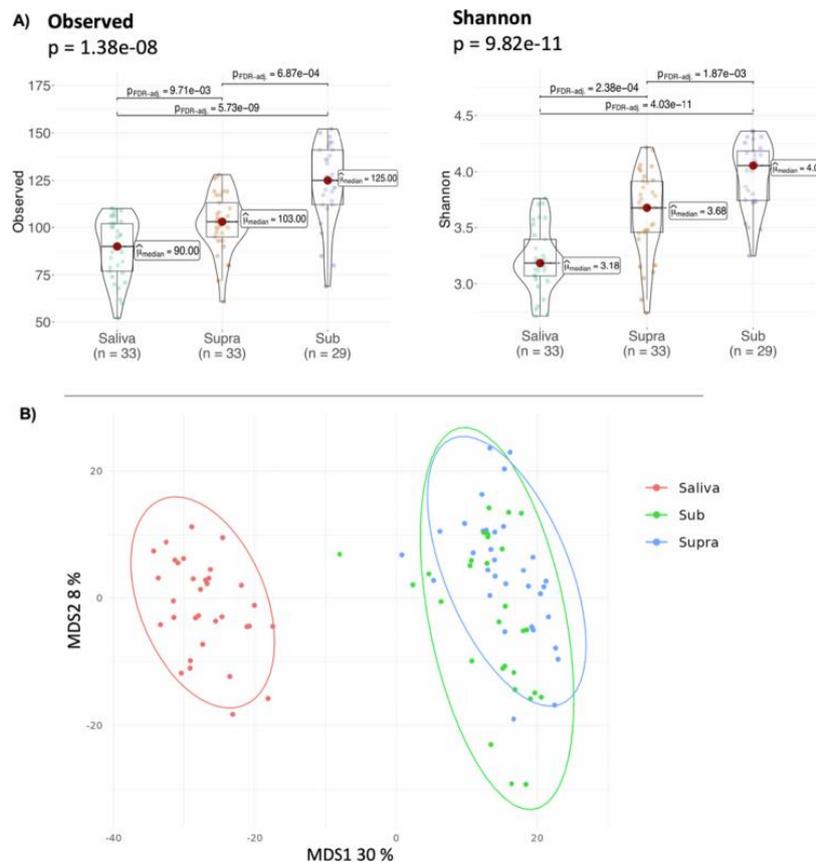
3. RESULTS AND DISCUSSION

The transition from conventional to digital orthodontic workflows represents not only a technological evolution but also a potential biological shift in treatment-related oral conditions. One of the primary advantages of digital orthodontics lies in appliance customization, which allows for

smoother surfaces, improved marginal adaptation, and enhanced precision in force application. These characteristics may significantly reduce microbial adhesion when compared to conventional brackets, which are known to create plaque-retentive niches (Cunha; Barbosa; Palma, 2021).

Clear aligner therapy, considered a hallmark of digital orthodontics, has been consistently associated with lower plaque accumulation due to its removable design. This feature enables patients to maintain routine oral hygiene practices more effectively, including toothbrushing and interdental cleaning. Differences in microbial diversity between saliva and plaque-associated niches highlight the importance of minimizing plaque retention to preserve a more balanced salivary microbiome (Figure 1) (Peregrina *et al.*, 2025).

Figure 1. Overall microbial composition across different oral niches. (A) Alpha diversity measured by Observed and Shannon indices in saliva, supragingival, and subgingival plaque samples, demonstrating significant differences in microbial richness and evenness. (B) Beta diversity analysis (MDS) showing distinct microbial community structures among oral niches. These findings highlight the biological relevance of plaque control strategies in maintaining salivary microbiome balance.



Source: Peregrina *et al.* (2025).



The replacement of conventional impression techniques with intraoral scanning represents another relevant factor. Traditional impression materials may temporarily alter salivary flow, oral pH, and patient comfort. In contrast, digital impressions are faster, less invasive, and better tolerated, reducing salivary stress responses that could influence microbial composition and biofilm dynamics (Yuzbasioglu *et al.*, 2014).

Digitally planned tooth movements also contribute to biological stability by promoting controlled and optimized force delivery. Excessive or poorly distributed forces are associated with tissue trauma, inflammation, and increased gingival crevicular fluid, conditions that favor dysbiotic microbial shifts. By minimizing such adverse effects, digital planning may indirectly support microbial homeostasis (Levrini *et al.*, 2026).

Treatment duration is a critical determinant of orthodontic-related microbial changes. Digital workflows frequently shorten treatment time through precise virtual planning, fewer appliance adjustments, and reduced chair-time. Shorter exposure to orthodontic appliances may limit long-term disruptions of the oral microbiome, decreasing cumulative inflammatory burden (Volovic *et al.*, 2023).

Several studies assessing periodontal indices during aligner therapy have reported lower levels of gingival inflammation compared to fixed appliance treatment. Reduced gingival inflammation is closely associated with decreased prevalence of periodontal pathogens, reinforcing the link between appliance design, tissue response, and microbial balance (Crego-Ruiz; Jorba-García, 2023).

Salivary flow dynamics are also influenced by appliance morphology. Bulky conventional appliances can interfere with physiological salivary clearance, impairing the natural washing effect of saliva. In contrast, slim digital appliances and aligners allow more uniform saliva distribution across dental surfaces, enhancing mechanical cleansing and antimicrobial action. (Dallel *et al.*, 2020).

Digital orthodontics may further contribute to the preservation of salivary antimicrobial components, such as immunoglobulin A, lysozyme, and defensins. By minimizing chronic mechanical irritation and inflammatory stress, digital systems may support the maintenance of these protective salivary factors, which play a central role in microbial regulation (Jing *et al.*, 2019).

Patient compliance represents another key variable. Digital orthodontic systems frequently incorporate monitoring technologies, mobile applications, and remote follow-up tools that enhance adherence to treatment protocols. Improved compliance is strongly associated with better oral hygiene behaviors, indirectly favoring a healthier salivary microbiome (Wafaie *et al.*, 2023).



Despite these promising associations, current evidence remains largely indirect. Few studies have directly quantified changes in the salivary microbiome of patients undergoing digital orthodontic treatment using high-throughput molecular techniques such as 16S rRNA sequencing or metagenomic analysis (Zhao *et al.*, 2020b).

The absence of standardized microbiome assessment protocols further limits cross-study comparisons. Variations in sampling methods, sequencing platforms, analysis pipelines, and timing of sample collection contribute to heterogeneous and sometimes inconclusive findings (Lehr *et al.*, 2025).

Nevertheless, the biological plausibility linking digital orthodontics to microbial modulation is robust. Reduced plaque retention, improved hygiene accessibility, decreased inflammation, and enhanced salivary function are well-established determinants of microbiome stability and oral health (Sun *et al.*, 2018).

From a preventive dentistry perspective, digital orthodontic workflows may represent a strategic approach to minimizing treatment-related oral complications, particularly in patients at elevated risk for caries or periodontal disease. This aspect highlights the potential role of digital orthodontics not only as a corrective modality but also as a preventive tool (Sangalli *et al.*, 2021).

The integration of digital technologies in orthodontics appears to extend beyond mechanical efficiency and esthetic predictability, emerging as a potential modulator of the oral biological environment. This paradigm shift reinforces the need to consider biological outcomes alongside technological advancements in contemporary orthodontic practice.

4. CONCLUSION

This narrative literature review suggests that digital orthodontic workflows may extend their impact beyond mechanical efficiency and esthetic predictability, potentially influencing the oral biological environment, particularly the salivary microbiome. By enabling appliance customization, reducing plaque-retentive surfaces, shortening treatment duration, and improving patient adherence to oral hygiene practices, digital orthodontic approaches may contribute to a more stable microbial balance during orthodontic treatment.

Although direct microbiome-focused evidence remains limited, the biological plausibility supporting this association is strong. Reduced plaque accumulation, minimized gingival inflammation,



improved salivary flow dynamics, and preservation of salivary antimicrobial components collectively represent key mechanisms through which digital orthodontics may favor oral microbiome homeostasis.

From a clinical perspective, these findings highlight the potential role of digital orthodontics as a preventive adjunct, particularly for patients at increased risk of caries or periodontal disease. However, the absence of longitudinal, controlled studies using standardized microbiome assessment methodologies limits definitive conclusions.

Future research should prioritize well-designed clinical trials and longitudinal cohort studies comparing digital and conventional orthodontic modalities, with direct evaluation of salivary and plaque microbiome profiles. Such investigations are essential to clarify causality, establish evidence-based guidelines, and fully elucidate the biological implications of digital orthodontic technologies in contemporary dental practice.



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