

## REVIEW ARTICLE

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# A Comprehensive Analysis of Periodontal Risk in Clear Aligner Users: Focus on Wear Duration, Patient Compliance, Advancements in AI Technology and Biomarker

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Clear aligners have become a popular alternative to fixed orthodontic appliances due to their aesthetic and hygienic advantages. However, their long-term impact on periodontal health remains underexplored, particularly concerning wear duration and patient compliance. This review aims to evaluate the periodontal effects of long-term clear aligner use, examine the role of patient compliance and wear time, and explore how emerging technologies like artificial intelligence (AI) and biomarkers can aid in monitoring periodontal risk. A narrative literature review was conducted using recent literature (2019 until May 2024) were identified through searches of PubMed, Scopus, and ScienceDirect. The search used keywords and MeSH terms and focused on studies addressing clear aligners, periodontal health, compliance, and digital or biomolecular monitoring tools. Findings indicate that clear aligners are generally associated with improved periodontal outcomes compared to braces, provided patients maintain oral hygiene and wear aligners 20–22 hours daily. Non-compliance increases the risk of gingival inflammation and microbial imbalance. Technological tools, including mobile apps and AI, enhance treatment adherence and enable early detection of periodontal changes. Additionally, biomarkers like IL-1 $\beta$  and MMP-8 offer potential for non-invasive monitoring of inflammation during aligner therapy. Clear aligners are effective and safe when used as directed, with compliance playing a critical role in periodontal outcomes. The integration of AI and biomarker-based monitoring holds promise for personalized, preventive orthodontic care. Further long-term studies are needed to validate these tools in clinical practice.

**Keywords:** partificial intelligence, biomarker, clear aligner, patient compliance, periodontal health

## Introduction

Orthodontic treatment has undergone rapid advancements in recent years, particularly with the emergence of clear aligners as an alternative to conventional braces for correcting malocclusions.<sup>1</sup> Clear aligners offer several advantages, they are not only more comfortable and aesthetically pleasing, but also allow patients to remove them when eating or

brushing their teeth, making them more practical choice for daily life. Unsurprisingly, their popularity continues to rise, especially among socially active young adults.<sup>2</sup>

Despite these benefits in terms of comfort and appearance, the impact of clear aligners on periodontal health remains a subject of debate. Most existing studies have primarily focused on tooth movement efficiency or comparisons with fixed orthodontic appliances, often

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assessing only the short-term effects. In practice, however, patients using clear aligners over a period of time may still experience periodontal issues that should not be overlooked.<sup>3</sup>

One commonly cited advantage of clear aligners is their potential to support better oral hygiene compared to fixed appliances, which involve wires and brackets. However, this benefit largely depends on patient compliance. Since aligners are removable, their effectiveness relies on consistent wear. Patients who are not disciplined such as those wearing the aligners for less than 20 hours per day, may experience slower tooth movement, extended treatment duration, and an increased risk of periodontal inflammation.<sup>4</sup>

Unfortunately, there is still a lack of studies that directly examine the relationship between aligner compliance and clinical periodontal outcomes. In reality, objective parameters such as Gingival Index (GI), Plaque Index (PI), Bleeding on Probing (BOP), and Clinical Attachment Loss (CAL) are essential for thoroughly evaluating the periodontal impact during aligner therapy.<sup>5</sup>

In recent years, technology has also begun to play a crucial role in enhancing orthodontic care. For instance, artificial intelligence (AI) is now being used to assist dentists in analyzing tooth movement, monitoring patient compliance in real-time, and creating more personalized treatment plans. Moreover, research on periodontal biomarkers from gingival crevicular fluid and saliva is being developed to enable early and non-invasive detection of inflammation.<sup>6,7,8</sup>

Given the gaps in the current literature, this review aims to provide a comprehensive analysis of how long-term use of clear aligners affects periodontal health. Special focus will be placed on the duration of wear, patient compliance, and the potential application of modern technologies such as AI and biomarkers as part of a preventive and diagnostic approach to periodontal risk. However objective of this literature reviews are to evaluate the existing literature on the long-term effects of clear aligners on periodontal tissues, to examine the relationship between patient compliance in wearing clear aligners and clinical periodontal outcomes, and to identify the potential application of AI and biomarkers in the management of periodontal risk during clear aligner treatment.

## Method

### Study Design

This article was developed using a narrative literature review method, with selective keyword to searching and

selecting relevant sources. The primary focus is to analyze and synthesize recent scientific findings on the impact of clear aligner use on periodontal health, with special attention to variables such as duration of wear, patient compliance, and the role of technologies like AI and biomarkers.

### Inclusion and Exclusion Criteria

For this review, we included scientific papers published between 2019 and May. 2025 that examined clear aligners in the context of periodontal health. Eligible studies had to address at least one of the following topics: aligner-wear duration, patient compliance, or the integration of technologies such as artificial intelligence, monitoring applications, or biomarker analysis during clear-aligner therapy. Only peer-reviewed journal articles, including systematic reviews, meta-analyses, cohort studies, and randomized clinical trials (RCTs), were considered. Furthermore, all papers had to be written in English and available in full text so they could be thoroughly assessed. Conversely, we excluded publications that focused solely on conventional orthodontic appliances without comparing them to clear aligners. Single case reports or editorial opinion pieces lacking research-based evidence were also omitted. Studies conducted on animals or purely *in-vitro* models deemed clinically irrelevant to humans were excluded as well. Finally, any investigation that assessed tooth-movement efficiency without addressing periodontal outcomes was not considered.

### Sources and Search Database

The literature search was conducted through several reputable international scientific databases, including PubMed, ScienceDirect, Scopus, Wiley Online Library, SpringerLink, and Google Scholar for a supplementary source. All databases were accessed on April 2025 to collect the most recent and relevant articles.

### Stem Cells and Biomaterial Scaffolds

The search was performed using a combination of keywords and Boolean operators (AND, OR) to obtain more relevant results. Some of the keyword combinations used included as “Clear aligner” AND “periodontal health”, “Invisalign” AND “gingival inflammation” OR “plaque accumulation”, “Removable orthodontic appliance” AND “periodontitis”, “Clear aligner” AND “wear time” AND “periodontal status”, “Clear aligner” AND “patient compliance” AND “oral

hygiene”, “Clear aligner” AND “artificial intelligence” OR “mobile application”, and “Clear aligner” AND “biomarkers” AND “gingival crevicular fluid”. After the initial screening based on titles and abstracts, articles that met the inclusion criteria were further assessed through full-text reading.

### **Data Analysis Technique**

A narrative synthesis approach was used to analyze the literature. The selected articles were qualitatively assessed to identify and discussion focuses on the consistencies and discrepancies among study findings, allowing comparison of reported outcomes regarding periodontal changes during clear aligner therapy. Attention is also given to the key variables influencing periodontal health, such as oral hygiene status, aligner material, wear duration, and patient compliance. Moreover, the review evaluates scientific evidence supporting or contradicting the role of wear duration and patient compliance, highlighting their direct influence on plaque accumulation, gingival inflammation, and overall periodontal response. Additionally, emerging trends in digital technology and biomarker utilization are explored, particularly the use of mobile applications, artificial intelligence, and gingival crevicular fluid biomarkers for risk assessment and real-time periodontal monitoring.

Key findings from each article were compiled and summarized in **Table 1**, including details such as author name, year, study design, population, main focus, and key conclusions.

## **Result and Discussion**

### **Clear Aligners in Modern Orthodontics**

Technological advancements in orthodontics have significantly transformed the approach to treating malocclusion. One of the most notable innovations is the use of clear aligners, transparent orthodontic devices made from special thermoplastic materials. These aligners are custom-designed using CAD/CAM technology based on digital scans of the patient's mouth.<sup>9</sup>

The primary advantages of clear aligners include their removability, transparency, and greater comfort compared to traditional fixed appliances such as braces.<sup>5</sup> In addition to their aesthetic appeal, patients can remove the aligners during meals and oral hygiene routines, which facilitates easier daily maintenance.

This practicality has contributed to the increasing popularity of clear aligners, especially among adults and older teenagers who have greater aesthetic concerns.

The technology behind clear aligner systems allows for more precise treatment planning. This process involves intraoral scanning, the creation of a 3D digital model, and simulation of step by step tooth movement. This approach not only improves the accuracy of tooth movement but also shortens the overall treatment time for mild to moderate cases.<sup>10</sup>

### **Impact of Clear Aligners on Periodontal Health**

Despite their many advantages, the potential impact of clear aligners on periodontal tissues remains a concern in orthodontics. In general, the risk of periodontal disease during orthodontic treatment is closely related to plaque accumulation, changes in the oral microbiota, and inflammation of the supporting tissues. Compared to conventional appliances, aligners are easier to clean, and thus are believed to have a more favorable effect on gingival health.<sup>11</sup>

However, some studies have found that the use of aligners without adequate oral hygiene education can still lead to biofilm buildup and increased GI and BOP, particularly in hard to reach posterior regions.<sup>1,3</sup> Other contributing factors include smoking habits, a history of periodontitis, and the quality of aligner cleaning practices.

Furthermore, long-term aligner use may alter the composition of the oral microbiota, including increased levels of anaerobic bacteria such as *Porphyromonas gingivalis* and *Fusobacterium nucleatum*, which are known periodontal pathogens. These changes are more pronounced in patients with poor oral hygiene or those who wear aligners for more than 20 hours a day without proper cleaning.<sup>12</sup>

### **Duration of Aligner Use and Its Effect on Periodontal Tissues**

Daily wear time of clear aligners is a critical factor that determines both treatment success and periodontal risk. Most manufacturers recommend wearing aligners for 20 to 22 hours per day to achieve optimal results. However, this prolonged wear also creates challenges for oral hygiene, as the mouth remains covered for most of the day, creating an anaerobic environment conducive to bacterial growth.<sup>13</sup>

The continuous orthodontic pressure from aligners may trigger mild inflammatory responses in

the periodontal tissues.<sup>8,14</sup> If aligners are worn for long durations without breaks for cleaning, this inflammation could progress into more severe conditions, such as attachment loss and alveolar bone resorption.<sup>15</sup>

Longitudinal studies with follow-up periods longer than six months have reported a significant increase in BOP and gingival index among patients who did not maintain aligner hygiene. These findings suggest that extended use may become a risk factor unless supported by strict plaque control and oral hygiene protocols.<sup>16</sup>

### ***Patient Compliance as a Determinant of Clinical and Periodontal Success***

The removable nature of clear aligners means that treatment success heavily depends on patient compliance. Patients who do not consistently wear their aligners as instructed may experience irregular tooth movement and uneven orthodontic force distribution, which can increase the risk of periodontal trauma.<sup>5</sup> An observational study found that patients with high compliance ( $\geq 20$  hours/day) had lower plaque and gingival index scores, along with minimal inflammatory response.<sup>17</sup> Conversely, patients with poor compliance showed more frequent increases in BOP and plaque buildup, especially in the interdental areas.<sup>16</sup> To address this issue, mobile app based tracking and smart sensors are now being used to monitor patient compliance in real-time. These tools provide immediate feedback to both patients and dental professionals regarding daily wear time. Digital interventions have significantly improved compliance, with some studies reporting up to a 30% increase in daily aligner use.<sup>7,14</sup>

### ***Role of Technology and Biomarkers in Monitoring Periodontal Risk***

Technological innovations have made substantial contributions to monitoring periodontal risk during aligner therapy. One of the latest approaches involves the use of AI to analyze radiographic and intraoral images to detect early signs of bone resorption, gingival inflammation, or changes in alveolar bone levels.<sup>18</sup>

In addition, recent biochemical studies have started evaluating the role of biomarkers in gingival crevicular fluid as non-invasive indicators of inflammatory response. Molecules such as matrix metalloproteinase-8 (MMP-8) and interleukin-1 $\beta$  (IL-1 $\beta$ ) have been found to increase in patients showing early signs of periodontitis

during orthodontic treatment, including those using clear aligners. The detection of these biomarkers has promising potential as an early monitoring tool to prevent further progression of periodontal disease.<sup>1,3</sup>

The use of clear aligners as an alternative to traditional orthodontic treatment has rapidly increased over the past decade. This innovation has gained wide acceptance among patients due to its advantages in aesthetics, comfort, and ease of maintaining oral hygiene. Unlike conventional braces, clear aligners are removable and transparent, which not only enhances appearance but also allows better access for brushing and flossing. However, as their popularity grows, concerns have also emerged regarding their long-term impact on periodontal health.

Through a systematic analysis of 18 selected scientific articles, three main themes have emerged as the focus of this discussion: the duration of aligner wear, patient compliance, and the integration of modern technologies especially AI and biomarkers in monitoring periodontal risk.

### ***The Impact of Aligner Wear Duration on Periodontal Health***

The duration of aligner use is a critical factor that balances the effectiveness of tooth movement with periodontal tissue health. Most manufacturers recommend wearing aligners for at least 20–22 hours per day, showing that optimal wear duration helps stabilize plaque levels and prevent biofilm accumulation.<sup>11,18</sup>

Wearing aligners for less than the recommended duration can lead to inconsistent orthodontic pressure, which not only slows down tooth movement but may also cause inflammatory stress on the periodontal ligament. On the other hand, wearing aligners for excessively long periods without removing them for proper oral hygiene can create an anaerobic environment favorable for pathogenic bacteria like *Porphyromonas gingivalis*, a major contributor to periodontitis. Therefore, an optimal wear duration must be coupled with patient education, encouraging scheduled breaks to allow the periodontal tissues to adapt.<sup>12</sup>

### ***Patient Compliance in Aligner Use***

The flexibility of clear aligners is both a benefit and a challenge. Since they are removable, treatment success relies heavily on patient discipline. The patients using mobile applications to track their daily wear time showed a 30% increase in compliance and a significant reduction in gingival inflammation scores.<sup>7,19</sup>

Non-compliance is often influenced by external factors such as speech discomfort, eating habits, or simply forgetting to reinsert the aligners after removal. Therefore, continuous and personalized patient education by dental professionals is essential to reinforce the importance of consistent use. In the future, combining digital tools with therapeutic communication could become an ideal strategy to improve adherence to treatment protocols.<sup>14</sup>

### ***Effects of Aligners on Periodontal Parameters***

In general, clear aligners have shown a more favorable profile on periodontal parameters compared to fixed appliances. This is mainly due to their smooth surface and the absence of brackets or wires, which minimizes mechanical irritation and reduces plaque retention areas. Good oral hygiene, aligner use does not significantly increase plaque levels or BOP.<sup>1,9</sup>

However, this effect is not absolute. Longitudinal studies indicate that patients with poor brushing habits may still experience increased gingival index, particularly in posterior areas. This highlights the importance of comprehensive hygiene practices, even when using devices considered more hygiene.<sup>1,2</sup>

Other wise, aligners also can alter the composition of subgingival microbiota. By using orthodontics appliances, saliva composition were associated with an increase in anaerobic bacteria after treatment, suggesting a shift toward microbial imbalance or dysbiosis. Research emphasized a decreased presence of periodontopathogenic bacteria and overall enhancements in oral health indicators, including lower plaque levels and improved periodontal parameters, among patients undergoing treatment with clear aligners.<sup>20-21</sup>

Consistent with findings, the improved oral hygiene associated with clear aligners is largely due to their design, which allows for easier cleaning and reduces bacterial buildup compared to traditional fixed orthodontic appliances. The studies reviewed indicated that clear aligners, made from smooth plastic materials and lacking components like screws and brackets, offer fewer crevices for bacteria to accumulate. In contrast, fixed appliances with their brackets, wires, and rougher surfaces create more opportunities for bacterial adhesion and growth. Overall, clear aligners were shown to promote better oral hygiene

and a healthier oral microbiome, as evidenced by reduced bacterial loads and enhanced periodontal health.<sup>20-21</sup>

### ***The Role of Technology (AI and Biomarkers)***

One of the most promising aspects of clear aligner therapy today is the integration of data-driven technology. AI has been applied in planning tooth movement through 3D simulations and has evolved into a tool for monitoring patient compliance and predicting clinical outcomes. AI can detect aligner wear patterns and issue early alerts for treatment failure or signs of inflammation.<sup>5</sup>

Additionally, the use of biomarkers such as IL-1 $\beta$  and MMP-8 in gingival crevicular fluid has shown potential as a non-invasive method to detect early periodontal inflammation.<sup>6</sup> If integrated effectively in clinical practice, these technologies could enable a more personalized, responsive, and preventive approach in orthodontics.

The incorporation of advanced digital technology, particularly AI and biomolecular diagnostics, has marked a significant leap in the evolution of clear aligner orthodontics. Beyond improving the predictability of tooth movement, these innovations offer unprecedented capabilities in assessing biological responses, monitoring treatment adherence, and mitigating periodontal risk in a more dynamic and personalized manner.

### ***Artificial Intelligence: From Prediction to Prevention***

AI systems in orthodontics utilize machine learning, deep learning, and computer vision to analyze vast clinical datasets, including 3D intraoral scans, panoramic radiographs, CBCTs, and patient-reported behavioral data. These tools not only automate diagnostic tasks but also act as clinical assistants in guiding treatment progression. One of the most impactful areas of AI integration is in clear aligner therapy. In 3D treatment planning and tooth movement simulation, AI software can map dental arches with precision, calculate optimal force application vectors, and simulate biologically realistic movements that reduce iatrogenic risks to the periodontium. For real-time compliance tracking, technologies such as ThermoChron iButtons and smart wear sensors are embedded into aligners to log intraoral temperature patterns. These data, processed by AI, distinguish between actual wear and passive storage, which is crucial since reduced wear time has been strongly associated with plaque retention, poor salivary clearance, and increased periodontal burden.

**Table 1.** Studies in analysis of periodontal risk in clear aligner users.

Reference	Study Design	Main Focus	Sample Size	Key Findings
[22]	Meta-analysis	Plaque and gingival index	n = 720	Clear aligners were superior in maintaining periodontal health
[23]	Systematic review	Comparison of orthodontic appliances	n = 524	Wearing aligners for more than ~20 hours/day was associated with better periodontal outcomes
[24]	Cohort study	Patient compliance with AI applications	n = 60	AI-based applications improved compliance and reduced gingival inflammation
[21]	Longitudinal study	Changes in periodontal microbiota	n = 40	Periodontal microbiota remained more stable in aligner users
[3]	Clinical trial	Plaque accumulation during aligner use	n = 52	No significant increase in plaque accumulation when oral hygiene was maintained
[24]	Review	Artificial intelligence in orthodontics	–	AI can predict and analyze the risk of periodontal inflammation
[16]	Prospective study	IL-1 $\beta$ and MMP-8 biomarkers	n = 28	Biomarker levels increased in patients with poor compliance to aligner use

AI also plays a significant role in predictive analytics and adaptive treatment, analyzing patient-specific factors such as age, smoking status, systemic health, oral hygiene scores, and historical biomarker levels to estimate periodontal risk. Based on these insights, clinicians can tailor treatment pacing, adjust hygiene recall intervals, or even switch to fixed appliances when necessary. Remote monitoring and feedback systems, including tools like Dental Monitoring™ and Grin™, enable patients to scan their oral cavity using smartphones, with AI analyzing the images for signs of inflammation, gingival margin changes, papillary recession, or plaque coverage thereby supporting continuous periodontal surveillance between clinic visits. Additionally, AI-driven risk stratification models have emerged as powerful tools; for instance that convolutional

neural networks (CNNs) can predict early attachment loss using only clinical photographs, achieving accuracy rates exceeding 90%. Such models can be integrated into orthodontic screening protocols prior to aligner issuance, aiding in the identification of high-risk patients.

#### ***Biomarkers: The Molecular Lens into Periodontal Status***

Biomarkers represent quantifiable biological indicators of inflammation, tissue remodeling, or disease activity, and their role in orthodontics—particularly in clear aligner therapy is becoming increasingly central due to the subtle yet persistent changes in the gingival environment caused by continuous plastic appliance coverage. Among the most studied are biomarkers found in gingival crevicular fluid (GCF), traditionally used in periodontology but still highly relevant in orthodontics. Key GCF markers include

IL-1 $\beta$  and IL-6, which are potent inflammatory cytokines elevated in response to mechanical forces or biofilm accumulation; MMP-8 and MMP-9, collagenases that signal connective tissue degradation and are often elevated prior to visible attachment loss; Prostaglandin E2 (PGE2), a mediator of bone resorption significant in orthodontic tooth movement; and the RANKL/OPG ratio, a marker of osteoclastic activity useful in predicting alveolar bone loss.

Saliva biomarkers offer a non-invasive, rapid, and scalable alternative for monitoring oral health, with biosensor technology and lab-on-chip platforms enabling near-instant detection of cytokines, enzymes, and host-response markers. Compared to GCF, saliva collection is less technique-sensitive and reflects a broader inflammatory state, making it more suitable for integration into AI-assisted home monitoring systems. Recent research from 2023–2024 has emphasized the value of multi-biomarker panels such as IL-1 $\beta$ , MMP-8, TNF- $\alpha$ , and sCD14 which have demonstrated over 85% sensitivity in detecting early periodontal inflammation in clear aligner users. Emerging salivary markers are also being investigated, including DNA methylation changes, miRNA expression like miR-146a, oxidative stress markers such as 8-OHdG, and microbial signatures like *Porphyromonas gingivalis* levels, all of which show promise as real-time indicators of periodontal stress under orthodontic forces.

The most promising frontier lies in the integration of AI with biomarker monitoring to enable precision periodontal orthodontics. AI systems can analyze trends in salivary biomarker levels, compare them to baseline data, and flag deviations suggestive of inflammation, dysbiosis, or tissue stress. Machine learning algorithms are capable of predicting individual risk trajectories based on longitudinal biomarker data, enabling real-time adjustments to aligner protocols such as pausing treatment, increasing hygiene recall frequency, or recommending adjunctive periodontal therapies. AI-driven platforms like OrthoDx™ (currently in development) are exploring automated decision trees that combine digital scan metrics with patient-uploaded saliva test results, offering tailored clinical guidance and enhancing the safety and efficacy of clear aligner therapy.

### ***Challenges and Future Directions***

Despite promising results, several challenges remain in the clinical integration of biomarker diagnostics and AI

in orthodontics. One major issue is standardization, as variability in sample collection methods, assay sensitivity, and cutoff values can significantly affect the reliability and reproducibility of biomarker tests across diverse populations. Cost and accessibility also pose limitations; while point-of-care biosensor devices and AI platforms offer advanced capabilities, they remain cost-prohibitive in many clinical settings, although prices are expected to decrease with wider adoption and technological maturation. Regulatory approval presents another hurdle, as many salivary biomarker panels are still in experimental stages and have not yet received approval for routine use in orthodontic practice. Additionally, concerns around data privacy and integration must be addressed, particularly in AI-enabled systems that handle sensitive biological and behavioral patient data. Ensuring secure storage, ethical data usage, and compliance with healthcare privacy regulations is essential for the responsible deployment of these emerging technologies.

Looking ahead, the ideal model would involve a closed loop AI biological feedback system, where aligner treatment is dynamically adapted based on real-time patient-specific inflammatory status. Such systems could minimize iatrogenic harm, shorten treatment times, and maintain optimal periodontal health especially important for adult orthodontic patients or those with a history of periodontal compromise.

Integration of AI and salivary biomarker technology holds immense potential to transform clear aligner therapy into a highly individualized, biologically responsive, and preventive form of orthodontics. As digital and molecular diagnostics become increasingly refined, the clinician's role will evolve from a passive monitor to an active orchestrator of a complex, data-driven periodontal care continuum. Among that, interdisciplinary collaboration among general dentists, orthodontists, periodontists, and medical technology developers should be strengthened to create a more holistic, data-driven, and responsive system for evaluating and managing periodontal health during orthodontic treatment especially to clear aligner.

Overall, findings from various journals suggest that clear aligners are a relatively safe option for periodontal tissues provided that patient education and monitoring are properly implemented. Compared to traditional braces, aligners create a more favorable oral

environment for hygiene, yet the risk of inflammation remains if compliance and plaque control are lacking.

The integration of digital technology is emerging as a key solution in aligner therapy. Tracking apps, AI systems, and biomarker detection tools can enhance monitoring quality and enable earlier preventive actions against periodontal disease. Therefore, interdisciplinary collaboration among orthodontists, periodontists, and dental technology developers is crucial to establish more structured, personalized, and sustainable treatment protocols.

Although several studies provide supportive data, the existing body of literature still presents some limitations. These include the limited number of longitudinal studies lasting more than six months, small sample sizes, and the inconsistent application of biomarker technology in clinical practice. Moreover, most studies have been conducted on young and healthy populations, making it difficult to generalize the findings to patients with specific systemic conditions, such as diabetes or smoking habits.

## Conclusion

Based on the literature review, the following conclusions can be drawn as long-term use of clear aligners tends to be safer for periodontal tissues compared to conventional orthodontic appliances, provided that oral hygiene is maintained and aligners are worn according to the recommended daily duration. Patients who consistently wear their aligners for 20–22 hours per day demonstrate better clinical periodontal outcomes, including lower plaque and gingival index scores. Technologies such as artificial intelligence and biomarker monitoring hold great potential in helping to predict periodontal risk early and in supporting personalized, risk-based orthodontic care. Beside that, orthodontic treatment could begin integrating app or sensor based compliance monitoring technologies into their clear aligner treatment protocols.

## Authors' Contribution

MM conceived the study, conducted the literature review, analyzed the data, and drafted the manuscript. EN contributed to literature screening, data collection, manuscript revision, and visualization. FS supervised the study, contributed to the study design and methodology,

critically revised the manuscript, and approved the final version. All authors read and approved the final manuscript.

## Conflict of Interest

The authors declare that they have no conflict of interest related to the research, authorship, or publication of this article.

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