Vol. 18 (2026): Proceedings of 2026 International Conference on Smart Healthcare and Biomedical Engineering (ICSHBE 2026)
E-ISSN: 3105-0522 P-ISSN: 3105-0514
DOI: https://doi.org/10.70267/shbe.2026242247

Research Progress on Clinical Application of Clear Aligner Technology

Zitong Jiang*

Xiamen University, Xiamen, Fujian, China

**Corresponding author: Zitong Jiang.*

Abstract

In an era of growing global emphasis on oral health, the fitting of orthodontic appliances has become a major method in orthodontic treatment. Among these, the clinical use of clear aligners has increased globally year by year. Although clear aligner technology is a favored option in orthodontic treatment, it still faces critical limitations, including suboptimal treatment efficiency, restricted clinical indications, and inconsistent tooth movement. To resolve these issues and enhance clinical application, this study reviews literature published over the past 10 years on the development process, technical principles, and drawbacks of application appliances in invisible orthodontics. Finally, this review identifies key unresolved challenges, including insufficient final alignment accuracy, incorrect tooth movement predictions in digital modeling, and limited applicability to complex malocclusion cases. By delving into these challenges and emerging advanced trends, the paper will address gaps in existing research and provide targeted direction for further development and research. This insight will foster domestic promotion and digital advancement in orthodontics, including artificial intelligence-assisted tooth modeling and the prediction of precise tooth movement.

Keywords

clear aligner technology, malocclusion, 3D digital technology, orthodontic treatment, periodontal health

1. Introduction

Emerging as an innovative orthodontic modality, clear aligner technology has evolved rapidly, supported by 3D digitization and materials science, including 3D scanning to improve accuracy and efficiency, computer-aided design to deliver personalized treatment, and the application of molecular materials with distinct properties to control tooth movement direction. In contrast to traditional fixed orthodontics, which is based on clinical utilization rates and market scale, it has become a revolutionary force in orthodontic treatment. This technology not only offers appealing aesthetics, comfortable wear, and removable cleaning but also enables the prediction of orthodontic processes and outcomes using computer technology. As a result, it meets the contemporary adult demand for both aesthetic appearance and functional effectiveness in treatment and has become a major method for achieving dental alignment today [1]. Yet in clinical practice and technological advancement, several shortcomings remain, including the lack of systematic clinical guidelines for indications and contraindications, underdeveloped digital predictive capabilities, suboptimal control of efficacy, and insufficient research on the occurrence and prevention of comorbidities. These issues force clinicians to rely on personal experience for treatment planning, potentially increasing the risk of treatment failure. Different results in tooth movement compared with theoretical predictions also reduce patients' acceptance, potentially leading to decreased compliance.

Furthermore, associated complications may compromise treatment safety. For example, it can lead to uncomfortable conditions such as periodontal disease, affect root resorption, and cause tooth mobility, influencing tooth health to some extent. Hence, this review outlines the historical development, technical core, clinical application principle, comparison with traditional treatment, both ongoing challenges, and innovation directions of invisible orthodontic technology, aiming to provide a theoretical basis for standardized clinical application. On one hand, this review will optimize orthodontic treatment protocol and highlight key innovative directions. On the other hand, it will provide clinicians with evidence-based diagnostic principles to improve treatment success rates. Additionally, it will promote the in-depth integration of clear aligner technology with digital tools, such as AI-assisted prediction of tooth movement, big data analysis for treatment plan optimization, and 5G technology for remote follow-up guidance, elevating the technology to a higher level of standardization and advanced development.

2. Development Progress and Technical Core of Clear Aligner Technology

Since Dr. Kesling of the United States first proposed the use of rigid rubber to fabricate dental retainers for tooth movement in 1945, clear aligner technology has gradually been adopted in orthodontics. Subsequently, Dr. Sheridan in the USA introduced the RaintreeEssix orthodontic technology system, which promotes the widespread clinical use of clear aligners. In 1997, Align Company pioneered the integration of digital technologies into orthodontic treatment, marking a milestone in the development of invisible orthodontics. In China, as attention to orthodontic aesthetics grows, bracket-free invisible orthodontics has also seen significant advances in research and technology [1]. Over the past 50 years, clear aligner technology has become one of the most popular orthodontic treatments today. Using advanced technologies such as 3D intraoral scanning, computer-aided design (CAD), and impression technology, clear aligners digitally scan the dentition and fabricate personalized bracketless invisible orthodontic appliances. Besides, when necessary, attachments and other functional components are added to improve tooth movement control, ensuring that orthodontic treatment proceeds in accordance with the pre-designed treatment plan.

Currently, clear aligners have become increasingly prevalent, and a comprehensive diagnosis and treatment system has been established [2]. In the process of making a personalized invisible orthodontic appliance, the application of computer technology is fundamental to achieving precision orthodontics, and the utilization of this technological principle is more complex than we think. The core biomechanical mechanism lies in the elastic deformation of the aligner material: each aligner is prefabricated with a specific tooth position that deviates from the patient's current dentition. When worn, the aligner undergoes elastic deformation, generating a continuous, gentle orthodontic force on the teeth. This force is transmitted to the periodontal ligament, triggering bone remodeling, as resorption on the pressure side and apposition on the tension side, which gradually moves the teeth to the target position according to the treatment plan. The complexity of this process arises from the fact that different teeth require distinct orthodontic movement patterns, and each tooth has unique mechanical properties and periodontal support conditions, resulting in varying degrees of force-control requirements.

Additionally, the magnitude and direction of orthodontic force required for treatment differ across tooth types and movement directions. The key role of computer technology is to analyze tooth movement accurately, digitally model the dentition, and predict the entire treatment process. With the support of these digital technologies, a series of sequential invisible aligners is designed for different treatment stages. Each aligner delivers a controlled, gentle force to the teeth, gradually shifting them toward the desired position. Ultimately, the ideal occlusal alignment is achieved through this multi-stage, complex process [1, 3]. With the continuous development of digital technology, bracketless invisible orthodontic appliances are becoming increasingly sophisticated, making overall orthodontic treatment smoother and further enhancing their clinical application value.

3. Clinical Application Standards and Efficacy Comparison of Clear Aligner Technology

3.1 Clinical Indications and Contraindications

The key to guaranteeing clinical efficacy is the strict control of clinical indications and contraindications. From a clinical perspective, bracket-free invisible orthodontics is no longer limited to mild crowding, diastemata, and post-orthodontic relapse; it can also be applied to varying degrees of dental crowding and mild-to-moderate skeletal malalignment. Meanwhile, this technology has also been favored by adult patients for the recovery of orthodontic treatment, due to its superior aesthetic appearance [4, 5]. However, from the perspective of clinical contraindications, clear aligner technology still faces limitations, such as poor anchorage control, limited three-dimensional planar control, and teet mesial tilting of adjacent teeth toward the extraction socket. Consequently, invisible aligners are inferior to fixed appliances in cases involving tooth extraction. Severe dental crowding clinical studies have demonstrated that clear aligners achieve an alignment success rate of approximately 92% in mild-to-moderate crowding, compared to only 68% in severe crowding cases. In comparison, fixed appliances maintain a 89% success rate across all severity levels [5, 6]. Therefore, to achieve optimal clinical outcomes, clinicians must strictly adhere to evidence-based clinical indications and contraindications.

3.2 Comparison with Traditional Orthodontic Appliances

Relevant clinical trials have shown that, compared with traditional fixed orthodontics, clear aligner treatment is associated with a higher prevalence of suboptimal occlusal outcomes, such as posterior open bite and reduced occlusal contacts, leading to increased patient dissatisfaction and a higher treatment failure rate [6]. Furthermore, controlling root movement is more difficult with clear aligners than with fixed orthodontic appliances, especially when treating without attachments [7]. This is due to unresolved biomechanical limitations: unlike fixed appliances, which can visualize both crown and root movement, clear aligners only reflect changes in crown movement, which cannot accurately reflect the patient’s tooth movement and overall occlusal status [8]. To understand the theoretical mechanisms of tooth movement, an in-depth investigation of force transmission mechanisms is essential. However, the treatment mechanism of transparent orthodontic appliances is more complex than that of fixed appliances, making it difficult to figure out and study [8]. From the perspective of patient diagnosis and treatment experience, bracketless invisible orthodontic appliances offer advantages in plaque removal, enabling better maintenance of optimal periodontal conditions, which distinguishes them from traditional fixed orthodontic appliances. Clinical data indicate that clear aligner patients exhibit significantly lower plaque index (PI) and sulcus bleeding index (SBI) scores during treatment, with a 35% lower incidence of gingival inflammation and a 42% lower risk of periodontitis compared to fixed appliance patients, despite the presence of minor gaps that may harbor bacterial growth [9,10].

4. Existing Issues and Research Hotspots in Clinical Application of Clear Aligner Technology

4.1 Biomechanical Limitations and Clinical Challenges

Although invisible orthodontic technology without brackets has become widely adopted in recent years, several unresolved issues remain. For instance, due to the inherent properties of aligner materials, varying degrees of reduction in tooth movement efficiency occur across different movement directions, which prevents the actual orthodontic process from strictly following the 3D design plan. This leads to virtual overcorrection easily, which is one of the reasons for higher non-acceptance and failure rates [4]. In addition, when clear aligners exhibit distinct functional orientations for different treatment stages and target effects. Consequently, clinicians must integrate multiple factors comprehensively, including the expected patient treatment outcome, treatment duration, clinical practicality, and the aesthetics and comfort of the appliance. Thus, this places significant demands on clinicians’ experience and expertise, meaning that clear aligner technology requires a higher level of clinical skill than scientific application of traditional fixed appliances [2, 4].

4.2 Digital Technology Integration and Material Science Innovation

In recent years, the application of 3D digital technology in dental model construction has become increasingly prevalent. Research has integrated dental models generated from cone-beam CT scans with crown models derived from laser scanning, effectively establishing high-precision digital dental models [3]. As a result, forming high-precision digital models is effective. Clinical experience has demonstrated that the appropriate use of attachments can effectively prevent dental inclination, making material science a key research hotspot. Based on the mechanical properties of different materials, various attachment types have been designed to facilitate more personalized orthodontic treatment [5]. In addition, the application of the torque ridge to improve anterior tooth torque control and micro-screw-enhanced anchorage represents critical directions for further research. Therefore, with the continuous development of invisible orthodontic materials, attachments, and auxiliary devices, clear aligner treatment has become increasingly accurate, and its clinical application scope has gradually expanded. For instance, orthodontists have attempted to use invisible aligners in the treatment of dental crowding and malalignment of the sagittal relationship, achieving satisfactory clinical outcomes [5]. With these advancements, it is anticipated that patients' acceptance will improve and that treatment effectiveness will be significantly enhanced.

5. Discussion

Reviewing the development history, core technology, clinical application regulations, and current challenges of clear aligner technology, this article systematically outlines these aspects. As an integration of digital technology and orthodontics, bracketless invisible orthodontics have realized personalized treatment and digital solutions. Leveraging CAD/CAM and 3D printing technologies, it demonstrates core advantages, including superior aesthetics, comfort, and removability. Through software and digital technology, it not only improves patient compliance with treatment but also delivers significant benefits in maintaining periodontal health. Compared with fixed orthodontic appliances, this technology is easier to clean and can effectively reduce the risk of periodontitis and gingivitis. As a result, it is emerging as the preferred treatment option for mild to moderate malocclusion. However, various factors also constrain the clinical application of this technology. For example, due to material properties, the effectiveness of tooth movement varies by direction, leading to discrepancies between virtual simulations and actual clinical outcomes that can result in virtual excess correction. Insufficient anchorage support and suboptimal planar control also render clear aligner technology less effective than fixed orthodontic appliances in treating complex cases, such as tooth extraction correction and severe dental crowding. Additionally, given the significantly greater demands on clinicians, the orthodontic plan must consider a range of factors, including the patient's malocclusion type and severity, as well as the patient's level of compliance. Considering the various directions of such an orthodontic treatment, it is unavoidable that we cannot rely solely on digital technology to achieve precise treatment throughout the entire process.

The advancement of digital technology opened new pathways for the development of clear aligner technology. For example, the use of a high-precision orthodontic model combining cone beam CT and laser scanning dramatically improves treatment accuracy; elaborate attachments, designed after careful consideration, enhance treatment personalization; and the application of auxiliary devices, such as "torque crest" and micro screw support, provides a more diversified force profile. By combining all of these technologies, the bracesless invisible orthodontic technique has not only expanded its clinical applications but is now also used to treat certain complex orthodontic cases. As a result, this has not only driven the technological sophistication of clear aligners but also enhanced their clinical value in orthodontic treatment.

In the future, further development of this technology requires attention to addressing its core technical challenges. On the one hand, it is essential to tackle challenges in materials science and develop innovative orthodontic materials that accommodate multi-directional tooth movement. On the other hand, deep integration of this technology with big data and artificial intelligence is needed, alongside the optimization of digital simulation techniques to achieve greater precision and personalization in orthodontic treatment. In clinical practice, it is critical to refine the guidelines for this technology's use, including improving the application norms for indications and contraindications. For example, clear aligner technology is suitable for mild dental crowding and mild to moderate malocclusion. In severe dental crowding, fixed orthodontic treatment should still be the primary approach to improve treatment effectiveness. To enhance clinicals' problem-solving abilities in clinical practical processes, it is important to strengthen their professional skills training. Ultimately, this will drive breakthroughs in clear aligner technology for the treatment of complex orthodontic cases, enhancing its clinical value and providing higher-quality, more personalized treatment solutions for patients.

6. Conclusion

Through a systematic discussion of the clinical application progress of non-bracket invisible orthodontic technology, this study clarifies that this technology has been widely used for the correction of mild to moderate malocclusion, supported by 3D digitalization and other related technologies. However, fixed orthodontic appliances still yield superior results in certain treatment scenarios, such as when tooth extraction is required. While orthodontists must still base patient treatment on comprehensive clinical factors and professional experience, and cannot rely entirely on 3D technology and orthodontic prediction systems, evidence suggests that this technology will continue to advance toward greater accuracy and personalization. With the development of digital technology, clear aligner therapy will become increasingly independent. From the perspective of development trends, future research should focus on addressing material science issues in invisible technology without brackets to improve its force control and durability. It is also important to integrate clear aligner technology with artificial intelligence and big data to optimize the precision and personalization of orthodontic solutions. Finally, efforts should be made to expand its clinical application scope and enhance its use across different orthodontic treatments. In short, this study begins with developmental research on brachetless invisible orthodontic technology, intuitively outlining its advantages and disadvantages in current clinical practice. It highlights the need to combine this technology with related digital innovations, which assist researchers in this field in understanding the importance of clear aligner technology and in outlining directions for technological innovation and future challenges.

References

[1] Bai, Y. X., & Wang, B. K. (2007). Bracket-free invisible orthodontic technology: Opportunities and challenges in orthodontics. West China Journal of Stomatology, 25(6), 521–524.

[2] Weir, T. (2017). Clear aligners in orthodontic treatment. Australian Dental Journal, 62(1), 58-62, https://doi.org/10.1111/adj.12454

[3] Pan, T. T., & Fang, B. (2015). Research progress on factors affecting the efficacy of bracket-free invisible orthodontics. International Journal of Oral and Maxillofacial Surgery, 42(3), 364–366.

[4] Liu, Y. (2017). Advantages and disadvantages of clinical application of bracket-free invisible orthodontics. Chinese Journal of Stomatology, 52(9), 538–542. https://doi.org/10.3760/cma.j.issn.1002-0098.2017.09.005

[5] Zhang, Y. F., & Li, W. R. (2017). Clinical application progress of bracket-free invisible orthodontics. Chinese Journal of Orthodontics, 24(2), 82–85. https://doi.org/10.3760/cma.j.issn.1674-5760.2017.02.005

[6] Rossini, G., Parrini, S., Castroflorio, T., Deregibus, A., & Debernardi, C. L. (2015). Efficacy of clear aligners in controlling orthodontic tooth movement. The Angle Orthodontist, 85(5), 881–889. https://doi. org/10. 2319/061614-436. 1

[7] Papageorgiou, S. N., et al. (2020). Treatment outcome with aligners and fixed appliances. European Journal of Orthodontics, 42(3), 245-252. https://doi.org/10.1093/ejo/cjz094

[8] Jiang, T., et al. (2021). Efficacy of incisor movement with clear aligners. American Journal of Orthodontics and Dentofacial Orthopedics. 160(4), 512-518. https://doi.org/10.1016/j.ajodo.2020.10.014

[9] Li, W., & Huang, Y. T. (2017). Clinical observation of the effect of bracket-free invisible orthodontic appliances and traditional fixed appliances on patients' periodontal health. Practical Journal of Stomatology, 33(2), 270–272.

[10] Sun, M. Y., Huang, Q. B., Wang, K. H., Lou, J. Y., Cai, Y., & Zhou, Y. (2018). Effect of bracket-free invisible orthodontic technology and traditional fixed orthodontic technology on periodontal health of

orthodontic patients. Journal of Stomatology, 38(2), 149–153. https://doi.org/10.13591/j.cnki.kqyx.2018.02.013

Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgment

This paper is an output of the science project.