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The Evolution of Clear Aligner Therapy: A Review of Aesthetic and Clinical Outcomes

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Abstract

This review evaluates the evolution and impact of clear aligner therapy (CAT) over the past 25 years. Since its introduction by Align Technology in 1999 as Invisalign, CAT has transformed orthodontic treatment with its clear, removable aligners.

Material and method: A comprehensive literature search was conducted across databases, including PubMed, Cochrane Library, ScienceDirect, Web of Science, Scopus, and Google Scholar, covering studies published from 2000 to 2025.

Results: The review highlights technological advancements, clinical effectiveness, patient satisfaction, limitations, and future prospects of CAT, providing insights into its role in contemporary orthodontics.

Conclusions: CAT has made significant strides in aesthetics, comfort, and convenience over the past 25 years. Despite technological advancements, challenges remain in achieving predictable outcomes for complex tooth movements. Success depends on appropriate case selection, patient compliance, and practitioner expertise.

Keywords: Clear Aligner Therapy; CAT; Invisalign; Comprehensive Review

Abbreviations: CAT: Clear Aligner Therapy, AOB: Anterior Open Bites, CBCT: Cone-Beam Computed Tomography, MA: Mandibular Advancement, TB: Twin Block, IOSs: Intraoral Scanners, SMPs: Shape Memory Polymers, FOA: Fixed Orthodontic Appliance, CAD: Computer-Aided Design, CAM: Computer Aided Manufacturing, AI: Artificial Intelligence

CVM: Cervical Vertebral Maturation, SNA: Sella Nasion to A point Angle, SNB: Sella Nasion to B point Angle, ANB: Difference between SNA and SNB angle, MP-SN: Mandibular plane to Sella–Nasion angle

Introduction

Origin and evolution

Orthodontic interventions have proven effective in addressing both functional and aesthetic concerns in adult and pediatric populations **[1]**. Fixed appliances (FA) remain a cornerstone of comprehensive orthodontic treatment due to their proven efficacy in managing a wide range of malocclusions. However, despite their clinical effectiveness, FAs are often associated with patient-reported concerns such as discomfort, challenges in maintaining oral hygiene, and temporary aesthetic compromises during treatment **[2,3]**. These limitations have fueled interest in alternative approaches, such as clear aligners, which aim to enhance patient comfort and satisfaction while maintaining treatment effectiveness.

In recent decades, significant advancements have been made—particularly with the development of clear aligner therapy (CAT). The concept of CAT originated with Harold D. Kesling's 1945 proposal to use sequential tooth positioners for gradual tooth movement, a technique that was limited by the technology of the time but laid the foundation for modern CAT utilizing thermoplastic materials **[4,5]**.

Thereafter, several significant innovations furthered and led to the development of CAT. The advancements marked key milestones in the refinement of CAT, laying the foundation for the sophisticated, effective aligners used in contemporary orthodontic practice including the emergence of the invisible retainers. This enhancement provided the effectiveness of the appliance but also contributed to improved stability and long-term treatment outcomes **[6-8]**. In 1999, Invisalign from Align Technology, Inc. was introduced and represented a paradigm shift from traditional braces by providing a nearly invisible, removable alternative for treating malocclusions and further technological innovation emerged thereafter **[9]**. This review explores the journey of CAT from its inception, analyzing its impact on clinical practice and patient care from 2000 to 2025.

Materials and Methods

A comprehensive literature search was conducted in databases such as PubMed, Cochrane Library, Science Direct, Web of Science, Scopus and Google scholar. Studies published from 2000-2025 were considered. The search strategy was conducted using the following keywords: ("Invisalign" OR "Clear aligners" OR" Clear aligners therapy"). The search was restricted to English language publications. The exclusion criteria comprised abstracts, review articles, discussions, case reports and case series. Two independent reviewers, JH and EN, screened titles, and abstracts for eligibility. Full-text articles were then assessed based on predefined inclusion criteria, which encompassed studies focusing on clear aligner therapy to evaluate the expectations towards clinical reality. Any disagreements were settled through conversation or the participation of two co-authors (CM and PU).

Aesthetics Outcomes of CAT

The advent of CAT has redefined aesthetic orthodontics, offering a modality that integrates functional correction with facial harmony. In contrast to traditional fixed appliances, clear aligners are fabricated from highly transparent, biocompatible thermoplastics that enable discreet and comfortable treatment **[10,11]**. This virtually invisible approach addresses a longstanding concern among adult patients: the aesthetic limitations of conventional braces **[12]**. CATs have been associated with enhanced psychosocial outcomes, including improved self-esteem and reduced treatment-related anxiety, largely due to their minimal visual impact during daily social and professional interactions **[12,13]**. From a craniofacial perspective, CATs contribute to favorable facial aesthetics by supporting natural soft tissue dynamics throughout the course of treatment. Their low-profile design and staged biomechanical forces minimize disruption to lip posture, incisor inclination, and midfacial contour **[14]**. This approach allows for precise dentoalveolar adjustments without compromising the delicate balance of the perioral region. As a result, clear aligners support aesthetic outcomes beyond dental alignment, including subtle improvements in nasolabial angle, facial symmetry, and lower facial height **[15]**. The absence of brackets and wires further reduces soft tissue irritation and preserves the integrity of the facial profile during orthodontic movement **[16]**.

The material science behind modern CATs plays a central role in sustaining their aesthetic superiority. Although physical, mechanical, chemical and morphological changes can be found due to oral exposure **[17,18]**. Advances in polymer technology have led to the development of aligner materials with exceptional clarity, stain resistance, and elastic memory. These materials maintain their translucency under daily functional stresses and exposure to staining agents, ensuring that the aligners remain virtually imperceptible throughout treatment. Their light transmission properties closely mimic those of natural enamel, enabling seamless integration into the oral environment **[19,20]**. In addition, morphological differences can determine the extent of orthodontic movements **[21]**. As innovations in aligner materials continue to evolve, the convergence of optical performance, biomechanical efficiency, and biocompatibility underscores the position of CATs as a leading solution in aesthetic dental medicine.

Clinical Applications and Effectiveness of CAT

CAT has proven effective in treating a range of malocclusions, particularly mild to moderate cases involving spacing, crowding, and non-complex bite issues. Innovations like attachments, power ridges, and mandibular advancement features have broadened its applicability, though its efficacy in complex cases remains under investigation. The integration of biomechanics principles has enabled CAT to address cases involving dental arch expansion, molar distalization, and combined orthodontic-orthopedic corrections **[22–25]**. Ke et al. **[11]** reported that both clear aligners and fixed appliances were effective in managing malocclusion. While clear aligners offered benefits such as segmented tooth movement and reduced treatment time, they were less effective than fixed appliances in achieving proper occlusal contacts, controlling tooth torque, and maintaining retention. A prior systematic review indicated that clear aligners may achieve clinically acceptable results comparable to fixed appliance therapy in managing the buccolingual inclination of upper and lower incisors **[26]**.

CAT in Open Bite Correction

Open bite malocclusions pose a significant challenge in orthodontics. CAT has demonstrated effectiveness in correcting mild to moderate open bites, particularly those caused by anterior tongue thrust or dentoalveolar discrepancies **[27–29]**. Strategies such as using elastics with aligners and incorporating attachments have enhanced outcomes. However, severe skeletal open bites often require combined approaches, including surgical interventions.

Harris et al. **[30]** recently demonstrated that open bite closure using clear aligners is achieved through a combination of extrusion of the maxillary and mandibular incisors, intrusion of the maxillary and mandibular molars, and mild mandibular autorotation. The treatment also resulted in significant retraction of the maxillary and mandibular incisors. Clear aligners have proven effective in reducing and managing the vertical dimension in patients with open bites. In their recent systematic review and meta-analysis, Correa et al. concluded that clear aligners can effectively manage adult anterior open bites (AOB) of up to approximately 2–3 mm, primarily due to extrusion of the incisors **[31]**. Eugene et al. similarly concluded that CAT primarily addresses anterior open bites through a combination of posterior teeth intrusion and anterior teeth extrusion **[28]**. Overall, while CAT demonstrates considerable effectiveness in treating mild to moderate open bite malocclusions, particularly through extrusion of anterior teeth and intrusion of posterior teeth, its limitations in severe skeletal open bite cases are evident. These complex cases often require a combination of approaches, including adjunctive treatments and surgical interventions, to achieve optimal outcomes. Nevertheless, clear aligners continue to offer a promising, non-invasive option for managing open bites, particularly in adult patients, with ongoing improvements in technique and precision.

CAT in Deep Bite Correction

CAT is effective in managing deep bite cases through intrusion of anterior teeth or extrusion of posterior teeth. Aligner staging, combined with precision cuts and attachments, ensures controlled tooth movements. Studies indicate favorable outcomes in mild to moderate deep bites, while severe cases may necessitate adjunctive therapies.

Khosravi et al. **[32]** concluded that Invisalign is relatively effective in controlling overbite, as it helps maintain a normal overbite in patients. However, their findings did not support the notion that posterior teeth undergo intrusion during Invisalign treatment. The study also suggested that deep bite improvement with Invisalign is primarily achieved through the proclination of mandibular incisors. Shahabuddin et al. reported significant discrepancies between planned and achieved vertical and faciolingual movements of individual teeth, with maxillary central incisors exhibiting the greatest difference. They determined that the accuracy of overbite correction in deep bite cases treated with Invisalign averaged 33%. Additionally, all vertical movements and changes in inclination showed statistically significant differences following the initial aligner use. The study emphasized the necessity of overcorrection and additional refinements for nearly all patients **[33]**. These findings highlight that clear aligner therapy has made significant strides in effectively managing deep bite cases, with promising outcomes in mild to moderate cases, while also demonstrating the potential for improvement through refinements and adjunctive therapies in more complex situations.

CAT in Molar Distalization

The upper molars can be distalized using either extra or intraoral forces, and various techniques have been developed in recent years to lessen reliance on patient compliance, such as intraoral appliances with or without skeletal anchorage. Despite these advancements, such devices can still lead to unwanted tipping of the maxillary molars or loss of anterior anchorage during distalization **[34]**. In recent decades, more adult patients have sought orthodontic treatments, preferring esthetic and comfortable alternatives to traditional fixed appliances. Invisalign (Align Technology, Inc.) has emerged as a solution to this demand, with several studies demonstrating its ability to achieve class II correction through sequential maxillary molar distalization in non-growing individuals **[22,35]**. However, clinical decisions should always be based on evidence with higher levels of support.

Saif et al. **[22]** found that CAT can be effectively used for adult patients requiring maxillary molar distalization, particularly when a mean movement of 2.6 mm is targeted. Clinicians should be cautious of potential counter effects when planning to move the maxillary molars distally, especially in patients with a significant initial overjet. This highlights the importance of considering overcorrection or the use of additional auxiliaries early in the treatment process. Ravera et al. **[34]** reached a similar conclusion, finding that CAT are effective in distalizing maxillary molars in non-growing individuals without causing significant vertical or mesiodistal tipping. As a result, there was no change in lower facial height by the end of the treatment. Therefore, clinicians can consider CAT as a viable option when planning treatment for adult patients needing 2 to 3 mm of maxillary molar distalization. Another study showed that using orthodontic aligners for upper molar distalization ensures strong control over the vertical dimension, making it a suitable option for treating high-angle or open bite patients. Additionally, it allows for accurate management of incisal torque without compromising anchorage during the treatment process **[36]**. In conclusion, orthodontic aligners offer an effective and reliable approach for upper molar distalization, particularly in high-angle or open bite patients, by maintaining vertical dimension control and anchorage while managing incisal torque with precision.

CAT in Arch Expansion

The use of CAT for expanding the upper arch represents an effective approach for patients with mild to moderate transverse maxillary deficiency or dental crowding, as it facilitates space creation to address crowding while simultaneously enhancing occlusal relationships by aligning the upper and lower dentitions **[37]**. However, Comprehensive clinical guidelines and evidence-based standards for CAT have yet to be fully established. For instance, the planned target positions in CAT often fail to correspond precisely with the achieved tooth movements, resulting in a notable degree of unpredictability **[38]**.

In recent 3D fine element method by Zhang et al. **[39]** their findings indicated that CAT resulted in buccal and distal tipping of the posterior teeth, lingual tipping of the anterior teeth, and incisor extrusion during maxillary arch expansion, without the incorporation of torque compensation. In the same line Morales-Burruezo et al. **[40]** illustrated that, during maxillary arch expansion achieved with CAT; the buccal tilt and efficiency of the posterior teeth progressively decrease from the first premolar to the first molar.

Transverse expansion achieved through CAT is effective in addressing non-skeletal malocclusions and alleviating dental crowding, enhancing the dental arch form by promoting dentoalveolar adaptations **[41]**. Loberto et al. **[42]** assessed the predictability of expansion in patients with early mixed dentition treated with clear aligners, evaluating the efficiency of the expansion both after the initial set of aligners and upon completion of the therapy. Their findings revealed that the predictability of expansion following the initial set of aligners was approximately 45.71 percent for the first deciduous molars, 48.70 percent for the second deciduous molars, and 41.52 percent for the deciduous canines. In the lower permanent molars, the overall predictability was 45.44 percent, with 46.67 percent observed at the first intermolar mesial width and 43.21 percent at the first intermolar distal width.

Additionally, Galluccio et al. **[43]** study on efficacy and accuracy of maxillary expansion with CAT on adult patients proved that the effectiveness of expansion averaged 55% at the intermolar gingival level and 43% at the canine gingival level, indicating that root movement was less pronounced than cusp movement, particularly at the canine and molar levels. These findings suggest that, despite the body movement planned in ClinCheck®, the achieved outcome is predominantly a coronal tipping movement of the tooth.

Figueiredo et al. **[44]** investigated the maxillary expansion and evaluated the relationship between CAT and changes in the maxillary alveolar bone using cone-beam computed tomography (CBCT). Results revealed that most teeth exhibited favorable cervical outcomes, with no significant reduction in alveolar bone thickness on the buccal surface. Similarly, no significant bone thickness loss was observed on the palatal surface of posterior teeth, canines, or lateral incisors. Notably, the first molars and premolars showed slight improvements in alveolar bone crest height and thickness, though these changes were clinically insignificant (<0.5 mm). However, central incisors experienced significant bone loss, including increased palatal bone dehiscence and reduced bone thickness, likely due to the bowstring effect caused by posterior expansion.

CAT in growing children, a class II correction

Align Technology (San Jose, CA, USA) introduced a functional appliance utilizing their patented materials, integrating growth modification principles with active anterior tooth movement, forming one of the two phases of treatment of mandibular advancement (MA) in growing children **[45]**. A recent study by Lombardo et al. **[46]** compared twin block (TB) and mandimbular advancement using CAT, their results proved that both treatments modalities demonstrated statistically significant and clinically relevant reduction in the ANB angle in the TB (–1.5° ± 1.4°) and MA (–1.5° ± 1.5°) groups compared to the untreated class 2 (UC2) group (+0.2° ± 0.3°). Additionally, for the Co-Gn parameter, both the TB and MA groups showed significant increases compared to the UC2 group, with total increases of 8.4 mm and 8.3 mm, respectively, in patients treated with the TB and MA appliances. The F22® clear aligner young appliance, a customizable aligner block positioned behind the upper incisors and designed to interlock with the lower aligner, promotes mandibular advancement and has garnered attention for managing Class II malocclusion in patients with CVM3–CMV4 stages. This versatile device can be effectively combined with adjunctive therapies, including Class II elastics, rapid palatal expansion to enhance treatment outcomes. Cremonini et al. **[47]** investigated the skeletal and dental effects of F22® appliance in 10 years children and the results demonstrated a statistically significant increase in the SNB angle, contributing to a reduction in the ANB angle. The forward advancement of Point B significantly reduced the sagittal skeletal discrepancy between the maxilla and mandible. Additionally, the occlusal plane distance between Points A and B decreased significantly. A slight but statistically significant increase in the MP-SN angle was also observed following treatment with the F22® Young appliance.

CATs present a more discreet option, offering advantages in comfort and aesthetics while enabling mandibular advancement through various design adaptations, as compared to twin block appliance. Ravera et al. **[48]** in their study patients at the CVM2 growth stage, significant changes from T0 to T1 included ANB reduction 1.30°, B Downs point advancement +2.23 mm, A: Po reduction -3.20 mm, and decreased upper incisor inclination -6.05°. At the CVM3 stage, common changes included an increase in palatal and mandibular plane angle (SpP^GoGn) +2.40° and mandibular length Co-Gn, +8.75 mm. Patients treated with Invisalign® MA showed a reduction in SpP^GoGn angle -2.97°.

Technological Innovations

Invisalign® (Align Technology, Santa Clara, CA, USA) has served as an aesthetic alternative to traditional orthodontic appliances for addressing mild to moderate malocclusions.Wafa Alswajy et al. **[49]** investigated the acurancy of the predictability of the ClinCheck® technology before and after the treatments and the study demonstrated a strong correlation between the achieved and predicted outcomes proposed by ClinCheck®. For the interincisal angle, the average difference was 0.20 ± 1.11 mm with an accuracy of 96.23%. In terms of upper intercanine width, the difference averaged 0.53 ± 1.05 mm with 97.97% accuracy, while for lower intermolar width, the average difference was 0.49 ± 2.08 mm with 97.72% accuracy.

Advancements in technology have enabled its use in more specialized applications within dentistry. With the digitization of dental procedures, including digital impressions and CAD/CAM solutions, the integration of 3D printing into various dental applications has become increasingly common (**Figure 1**). Lohfeld et al. **[50]** This study investigated the accuracy of 3D-printed models created with a desktop DLP printer, focusing on hollow and solid models at varying print angles. Results showed that 98% of 660 measurements fell within the clinically acceptable range, with only 15 deviations. Seven of eleven measured structures demonstrated consistent accuracy across 60 models. Minor inaccuracies were found in intermolar distance, molar crown height, canine crown height, and central incisor crown height. Notably, the solid-70° and solid-90° models exhibited complete clinical accuracy.

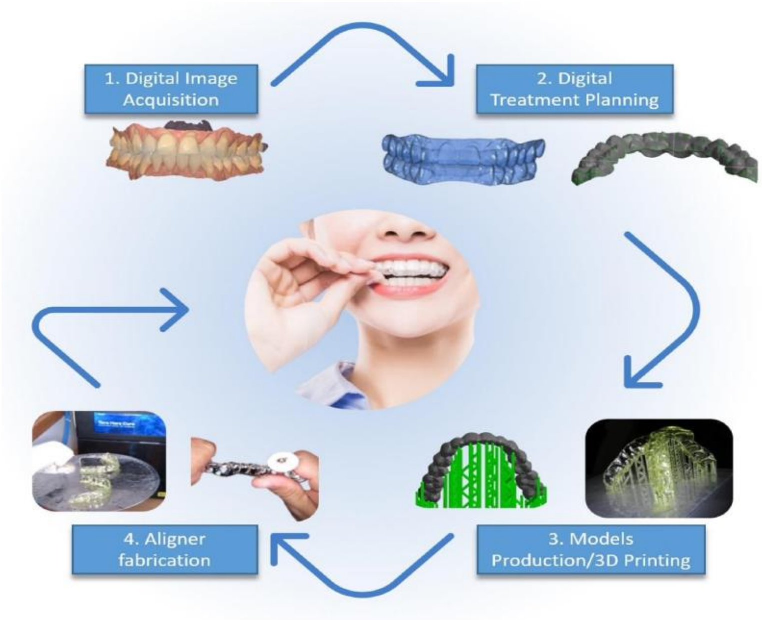

Figure 1. Workflow of generating clear aligners from 3D printing. Reproduced from Bichu YM et al. **[51]**. Advances in orthodontic clear aligner materials, Bioactive Materials, DOI: 10.1016/j.bioactmat.2022.10.006, Licensed under CC BY-NC-ND (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Intraoral scanners (IOSs) play a crucial role in digital dentistry, enabling the capture of intraoral optical impressions and the generation of detailed virtual models. Recent advancements in IOS technology have been marked by significant innovations in both hardware and software **[52]**. Schlenz et al. **[53]** reported that IOSs for caries detection rely on either fluorescence technology, using light at a wavelength of 415 nm, or near infrared imaging, which utilizes light wavelengths ranging from 727 nm to 850 nm. Depending on the manufacturer's design, IOSs can detect proximal carious lesions, occlusal carious lesions, or both in certain models.

According to Lee et al. **[54]** the use of orthodontic aligners for treating malocclusions has increased, alongside the rise of intraoral impressions and virtual treatment planning as alternatives to traditional methods. IOS not only assists in diagnostics and treatment planning but also helps monitor root position. By combining CBCT data with pre-treatment IOS scans, 3D tooth models are created (**Figure 2**). These models, integrated with post-treatment digital scans, allow for accurate root position predictions, removing the need for additional CBCT imaging.

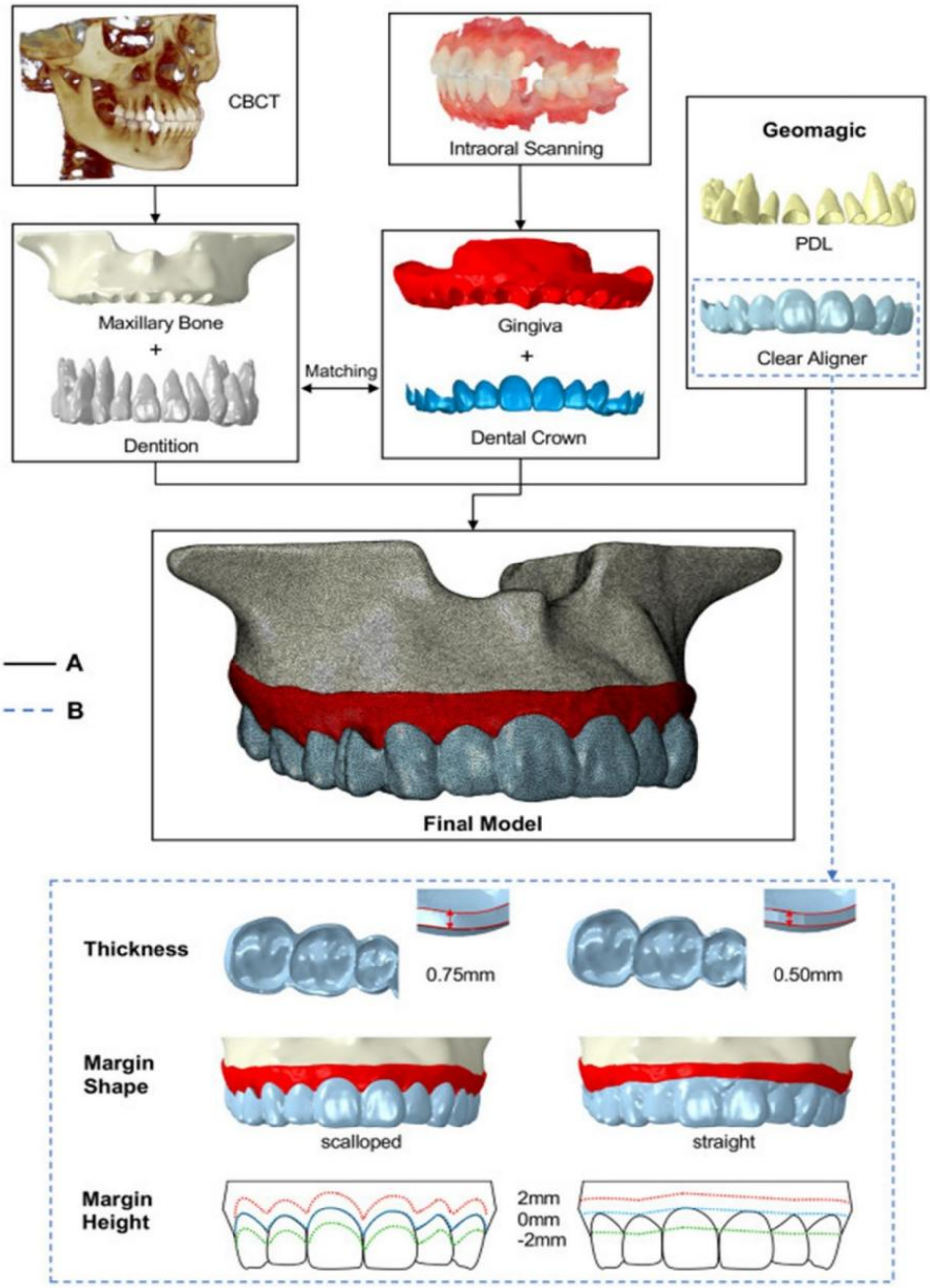

Figure 2. Combination of CBCT data and Intraoral scans (IOS) to create 3D models. Figure was adapted with permission from Ref. Lyu X et al. **[55]** granted by the copyright holder Elsevier, its licensors, and contributors, 2025

Shape Memory Materials in CAT

Shape memory materials are a category of smart materials that can change their macroscopic shape when exposed to a specific stimulus. They hold this altered shape temporarily and return to their original form once a different stimulus is applied **[56]**. Shape memory polymers (SMPs) offer low density, significant elastic deformation, and excellent chemical stability. They can be programmed to exhibit adjustable physical properties and are relatively transparent. These characteristics make SMPs an ideal candidate for use as a novel clear aligner material, potentially providing the aligner with a strong ability to recover its original shape **[57]**. ClearX system sheets, made of thermo-responsive shape memory polyurethane, offer the ability to recover their original shape after thermal activation. This material can potentially replace multiple traditional aligners with just one, reducing treatment time, costs, and the number of aligners needed, particularly in complex orthodontic treatments **[58]**.

Elshazly et al. **[59]** assessed the shape recovery of orthodontic aligners made from shape memory polymer using a typodont model. The results revealed that nearly 92.63% of the total planned correction could be achieved on a typodont through a single reforming step followed by two activation steps. After the first activation, the aligners produced an average additional movement of 0.66 mm, representing 55% of the intended shape memory shift, resulting in an overall movement of 1.6 mm, or 84.2% of the total planned movement. The second activation contributed an extra 0.15 mm, equating to 12.5% of the total planned movement, bringing the overall movement to 1.75 mm, or 92.63% of the planned correction.

Patient Compliance and Challenges

Invisalign® is an alternative to fixed orthodontic appliances (FOA), It provides the benefit of improved aesthetics and the convenience of being removable during eating, drinking, and oral hygiene routines. Although it's a relatively new treatment approach, there are limited studies comparing its effects on oral hygiene with those of FOA **[3]**.

Castilhos et al. **[60]** examined the perceptions of general public regarding comfort, satisfaction, and willingness to use various accessories in clear aligner therapy like hybrid treatment with esthetic braces, class II elastics, combination of aligners plus attachments and implants with aligners. The results for question one, “Would you feel comfortable undergoing this procedure?” revealed that CAT was rated significantly more comfortable than all other groups. Attachments, while less comfortable than CAT, were still considered noticeably more comfortable than other accessories, for question two, “Would you be satisfied if this procedure were necessary for your treatment?” (Yes, No), a notable difference was observed between CAT and the other groups. CAT demonstrated a significantly higher satisfaction rate compared to all other accessories.

Patient compliance is essential for successful clear aligner CAT and can be influenced by factors such as demographics, education level, doctor-patient interaction, and personality traits. Ghoneim et al. **[61]** examined the impact of characteristics on patient adherence to CATs, and they find that participants aged 12 to 34 demonstrated markedly higher compliance rates compared to older individuals. In addition, our research revealed that men were more compliant than women (72.2% vs. 40.8%). This finding, which is consistent with Timm et al., **[62]** emphasizes the need for gender-specific approaches to improve orthodontic adherence. It emphasizes how crucial it is to take gender variations into account when selecting a course of treatment. However, contrary to predictions, compliance was not significantly correlated with smiling satisfaction. This research casts doubt on the notion that patients who are unhappy with their looks are more inclined to stick with their treatment plans.

Research and Development

A significant advancement in orthodontics is the integration of digital technologies into clinical practice. The application of 3D imaging and computer-aided design (CAD) enables accurate visualization of dental structures and facilitates the tailored design of braces or aligners to meet the specific needs of individual patients. A study conducted by Alami et al. **[63]** highlighted that aligners not only offer a distinct aesthetic benefit compared to conventional braces but also enhance treatment effectiveness. This is made possible by enabling orthodontists to simulate and modify treatment plans prior to commencement.

The advancement of orthodontic appliances reflects not only technological progress but also a growing emphasis on meeting aesthetic preferences. While traditional metal braces remain effective, their perceived lack of visual appeal has driven a shift toward more discreet options. Alternatives such as ceramic braces, lingual braces, and clear aligners have gained popularity for their subtle and less noticeable appearance **[64]**.

D'Apuzzo **[65]** found that a substantial proportion of adult patients prioritize aesthetics over cost, favoring aligners and ceramic braces over traditional metal options. This preference has driven advancements in orthodontic appliances that combine functionality with visual appeal. Additionally, the growing influence of social media and the increased emphasis on maintaining a polished public image have further amplified the demand for aesthetically pleasing orthodontic solutions.

Societal Impact

Psychological and social factors play a crucial role in the experience of orthodontic treatment. Halawani et al. **[66]** their study proved that CAT demonstrated a positive impact on patients' psychological well-being compared to conventional braces. A significant number of patients reported enhanced self-esteem, attributed to the discreet appearance of aligners, which made them less obtrusive in social interactions.

Research conducted by Papageorgiou et al. **[64]** highlighted that the discreet nature of aligners significantly mitigates social anxieties commonly associated with orthodontic treatment. One notable example, shared by a participant, underscores this point: "I was always very self-conscious about my braces during meetings and social events. With aligners, I hardly think about them anymore, and my confidence has soared." This finding underscores the critical role of reduced visual impact in enhancing patients' social interactions and psychological well-being.

Future Prospects

The integration of 3D printing technology represents a transformative advancement in orthodontics, mirroring its impact across various medical fields. This innovation facilitates the rapid prototyping and customization of orthodontic appliances, including braces and aligners, resulting in reduced production time and costs. Consequently, it enhances patient accessibility and convenience, marking a significant step forward in modern orthodontic care **[65]**.

Virtual reality and augmented reality are set to transform patient consultations and treatment planning by enabling patients to visualize anticipated treatment outcomes, thereby facilitating informed decision-making and enhancing clinical education. Additionally, the growing use of intraoral scanners for real-time imaging enhances the precision of treatment planning while minimizing reliance on traditional impression techniques **[67]**.

The emergence of smart orthodontic devices with integrated sensors presents a promising innovation for the future. These devices have the potential to deliver real time data on tooth movement and oral hygiene, enabling both patients and practitioners to monitor progress and implement timely interventions or adjustments, thereby enhancing treatment efficiency **[63]**. Artificial intelligence (AI) and machine learning have the potential to transform orthodontic diagnostics and treatment planning. These technologies can optimize appliance selection and treatment duration by analyzing individual data, including growth patterns, lifestyle factors, and medical history. Finally, AI models offer unprecedented insights, enabling highly personalized and effective treatment strategies tailored to each patient **[68]**.

Conclusion

CAT has evolved significantly over the past 25 years, fulfilling many expectations regarding aesthetics, comfort, and convenience. However, its clinical effectiveness, particularly for complex tooth movements, still presents challenges. While advancements in technology and treatment protocols have improved outcomes, success remains dependent on proper case selection, patient compliance, and practitioner expertise. Ultimately, aligning initial expectations with clinical reality requires continued innovation and evidence-based practice to further enhance its efficacy and predictability in orthodontic care.

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