

Clear Aligners in Orthodontics: A Narrative Review of Stability and Success

Hattan S. Katib¹, Areej M. Hakami², Mashail Albalawei³, Saif A. Alhajri⁴, Mishal S. Alruwaily⁵, Moath I. Almusallam⁵, Ghaida H. Alqahtani⁶

1. Endodontics, King Fahd Hospital, Madinah, SAU 2. General Dentistry, Jazan University, Tabuk, SAU 3. General Dentistry, Tabuk National Dental Center, Tabuk, SAU 4. General Dentistry, Al Safwa Saudi Medical Company, Riyadh, SAU 5. General Dentistry, Imam Abdulrahman Bin Faisal University, Dammam, SAU 6. General Dentistry, Farabi dental college, jeddah, SAU

Corresponding author: Hattan S. Katib, hattan222333@gmail.com

Abstract

The implementation of Clear Aligner Therapy (CAT) in adult orthodontics exemplifies the integration of advanced technology in the dental healthcare sector. Representing a significant shift in modern orthodontics, CAT offers a convenient and aesthetic alternative to traditional fixed appliance treatments for mal-aligned dentition. This narrative review aims to explore the applicability of CAT, delineating its biomechanics, indications, contraindications, scope, limitations, and factors influencing long-term stability and successful outcomes. A comprehensive literature search was conducted using databases like Google Scholar, PubMed, Cereus, and the Cochrane Library. Articles were selected based on their relevance to clear aligners, without brand specificity, and covered a wide range of cases to establish CAT's scope and limitations. This review includes individual case studies, systemic reviews, comparative analyses, case reports, finite element analyses, and prospective and retrospective analyses, all contributing to a nuanced understanding of CAT's applicability and long-term treatment stability. The conclusion underscores CAT's growing acceptance in orthodontics, including its application in challenging cases, and highlights key determinants that bolster its long-term efficacy.

Categories: Dentistry

Keywords: invisalign, orthodontic patients, orthodontic management, clear aligner, orthodontic

Introduction And Background

The world is continuously progressing, and the dental healthcare setup is also experiencing the introduction of novelties and advanced technology for a long time. The implementation of Clear Aligner Treatment (CAT) in adult orthodontics is one such example. Clear Aligners represent a paradigm shift in modern orthodontics, providing a more convenient solution for repositioning mal-aligned dentition than conventional fixed orthodontic treatment. These thin plastic devices, made from semi-elastic polyurethane [1], are aesthetic, comfortable, and facilitate good oral hygiene maintenance, making them a preferable substitute to conventional metallic brackets [2], owing to the higher patient satisfaction rate and refinement of occlusal functionality [3].

They have undergone a series of evolutions to resemble and function as they do today. The history dates back to the origin of the tooth positioner system in orthodontics by Keslings in 1945, as an optimization appliance used in the final stages of treatment after de-banding [4]. The operational efficacy extended; the ideation was carried forward and underwent sequential developments until 1998 when the advancements in CAT by Align Technology Inc. took over the market [5].

The ongoing metamorphosis is what we are experiencing in present times; the integration of transparent thermoplastic materials, digitalization with CAD-CAM, stereolithography, and tooth-movement simulation software, i.e., ClinCheck. These breakthroughs transformed the course of treatment. Initially, their use was confined to minor tooth discrepancies and mild malocclusions; clear aligners were considered beneficial for partial tooth movements, leading to rapid case completion, whereas braces remained advantageous against a wide variety of tooth movements, i.e., root paralleling and torqueing, etc., and less relapse [6]. However, the incorporation of various auxiliaries and attachments with different biomechanics and unique construction methods has made it possible to treat complex cases with successful outcomes [2], which is further studied in this review. Moreover, some of the other positive features of CAT included good periodontal health due to accessible teeth and gum care, as the appliances are removable [7], and fewer appointments and emergency visits compared to braces [8]. The applicability of clear aligners has been studied in a variety of cases, but further investigation is needed to fully comment on their potential and wider scope. The long-term stability followed by a complete course of treatment with CAT accounts for its success, predictability, and effectiveness. Above all, the chances of relapse determine the prognosis of the outcome.

This review aims to critically assess the applicability, limitations, and scope of Clear Aligner Therapy (CAT).

It endeavors to link the outcomes from various malocclusion treatments to evaluate the overall stability of treatment with clear aligners. Furthermore, the review will identify key determinants that contribute to the long-term success of this treatment modality.

Review

Clear Aligner Biomechanics

As a removable appliance, Clear Aligners are most efficient at executing the simplest of all tooth movements, such as tipping. Their effectiveness in root uprighting in extraction cases for space closure, controlling tooth rotations, and extrusion has been intermittently successful, as further proven in a study by Ipek Tamer et al. [9]. Clear Aligners are driven by two systems: the first is the displacement-driven system, which favors less complicated movements like tipping and control of minor rotations. In this system, aligners are designed based on the proposed final location of the tooth, allowing the tooth to move or displace until it aligns with the aligner. The second is the force-driven system, which operates on biomechanical principles. The amount and type of force applied depend on the shape of the aligners, with each tooth receiving a specific magnitude and type of force as determined by ClinCheck software. This system's aligner details, such as pressure points, facilitate more complex tooth movements like uprighting and intrusion, and power ridges are used to control root torque. In contrast, the former system is better suited for achieving simpler tooth movements [9]. The latter system's effectiveness in complex cases still requires further investigation.

Clinical Applications of Clear Aligners

Scope and limitations

The biomechanics of Clear Aligners, as described above, present an interesting phenomenon that forms the basis of their scope and limitations. Understanding these aspects is fundamental to acknowledging the longevity, long-term predictability, and stability of Clear Aligner Treatment. Numerous studies have been conducted to establish their precise role in orthodontics. However, only a few have successfully discussed their potential functionality and emerging merits, thereby adding breadth to our understanding.

Indications and contraindications of Clear Aligner Therapy ;

The indications and contraindications of Clear Aligner Therapy (CAT) are critical for its successful application in orthodontic. The indications of CAT [10-11] include managing crowding and spacing issues between 1 to 5 mm, addressing deep overbites, particularly in class 2 division 2 cases that require intrusion or proclination of incisors, and treating narrow arches that are 4-6mm due to non-skeletal reasons and need expansion with moderate tipping of the teeth. CAT is also indicated for patients with fully erupted permanent teeth, in non-growing patients (late adolescents or adults), and for addressing relapse cases post fixed appliance treatment. Additionally, it's suitable for tooth movements following Inter-proximal Reduction (IPR) and staged distalization, as well as for space closure following the extraction of a lower incisor.

Conversely, there are specific contraindications for using CAT [10-11]. These include cases with crowding and spacing greater than 5 mm, skeletal Anterior-posterior (AP) discrepancies greater than 2mm, Centric Relation (CR) and Centric Occlusion (CO) mismatches, severely rotated teeth (more than 20 degrees), anterior and posterior open bite cases, extrusion of teeth, severely tipped teeth (more than 45 degrees), teeth with short clinical crowns, and cases involving multiple missing teeth. Understanding these limitations is crucial for the effective and appropriate application of CAT in orthodontic treatments.

This notion has been consistently reiterated: aligners began as a treatment modality for non-growing (adult) patients, mild to moderate malocclusions, and non-extraction cases. A study conducted by Chih-Ling Lin et al. [12] shared doubtful results about the effectiveness of CAT (Clear Aligner Therapy) as a therapeutic approach for minor orthodontic cases but established that fixed appliance therapy had a greater chance of success in maintaining occlusal contacts. Additionally, CAT showed limited success in tipping second molars for space closure, further confirming its limitations in extraction cases for space fulfillment [12].

However, in the extant literature, CAT has been studied in growing individuals and is further elaborated in this review. It has been implicated in moderate to severe malocclusions by utilizing bonded resin attachments on teeth to enhance the scope of the aligners [2]. As Weir et al. [2] further elaborated, the most complex tooth movements cannot occur solely through clear aligner therapy; they need to be supplemented with auxiliaries and a few geometric changes in aligners. These include the inclusion of bite ramps, pressure points, power ridges for complex root movements, and the addition of inter-maxillary elastics, considering IPR (Interproximal Reduction), using TADs (Temporary Anchorage Devices), power arms, and fixed expanders as with fixed orthodontic appliances, to increase the range of the appliance [2].

This is further confirmed by Xiujin Xing et al. [13], who noted that clear aligners have recently gained popularity in treating extraction cases and have been implicated in tooth rotations, molar distalization, and

arch expansion [13]. Further studies on the complicated intrusion and extrusion of teeth concluded that CAT was more efficient in controlling anterior extrusion than intrusion [12]. A modified aligner with a Z spring constructed was also studied for the correction of single-tooth crossbites and became an esthetic, reliable, and cheaper alternative for this purpose [14].

Some cases have been thoroughly assessed to comprehend the scope and applicability of clear aligner therapy, while others require further investigation and additional evidence to comment on its successful implementation and the potential for long-term treatment stability.

Open bite correction

An open bite is characterized by a lack of overlap between the maxillary and mandibular teeth, which can be treated by either extruding the anterior teeth, intruding the posterior teeth, or in some cases, both. As previously mentioned, open bite cases are considered complicated and generally contraindicated for treatment with clear aligners. However, as Proffit mentions [11], their treatment is possible with the use of auxiliaries and a combined approach. This is supported by a study conducted by Tarek El-Bialy [15], which concluded the same. The hybrid approach, using high-frequency vibration and clear aligners, made it possible to treat a severe case of an adult patient with Class III Skeletal malocclusion, open bite, and bimaxillary protrusion. The clear aligners successfully moved teeth into the extraction space of an extra premolar found in the lower left quadrant, leading to the resolution of the problem [15]. Another study by Heeyeon Suh et al. [16] investigated the role of CAT (Clear Aligner Therapy) in non-extraction cases, finding that approximately 94% of adult patients had their anterior open bite corrected. It was also found that clear aligners led to more vertical control by bringing about maxillary molar intrusion while keeping the position of the mandibular molars intact [16].

Waddah Sabouni et al. [17] studied the implication of clear aligners in the treatment of open bite, incorporating three cases: clear aligners alone, clear aligners with attachments and vertical elastics, and clear aligners with attachments and temporary anchorage devices. The research showed satisfactory success in all three scenarios, with auxiliaries treating more complex cases. It emphasized that these types of malocclusions responded better to treatment with clear aligners than fixed appliance therapy because they apply less extrusive force on posterior teeth, which are meant to be intruded in the treatment of open bite. The treatment of open bite with clear aligners involves the combined intrusion of maxillary and mandibular teeth and the combined extrusion of maxillary and mandibular anterior teeth [17].

Deep bite correction

Deep bite, characterized by excessive overlap of maxillary and mandibular teeth, is one of the most complicated cases to treat with clear aligners. Treatment typically involves the intrusion of incisors, extrusion of molars, or both, depending on the incisal show [18]. This process requires careful planning and has achieved limited success with clear aligners. One study found that the use of bite ramps created space for posterior teeth extrusion and anterior teeth intrusion, along with a controlled proclination [19].

Neal D. Kravitz et al. [20] also confirmed the difficulty in treating deep bite with clear aligners. However, the therapeutic approach has been altered with the incorporation of supporting auxiliaries. These include bite ramps for anterior teeth intrusion and disoccluding the posterior teeth for their extrusion, elastics for posterior teeth extrusion and proclination, and attachments to make aligners more retentive. Additionally, a virtual case setup, which visualizes the forces exerted for particular tooth movements rather than the final tooth position, has proven to be of great importance in planning such cases [20]. Furthermore, aligners with modified intrusion patterns can impact the forces exerted on incisors, canines, and premolars differently [21]. There are avenues of exploration that need to be looked into for a reliable and stable outcome.

CAT in mild to moderate cases

It is well-established that clear aligners are effective in treating mild to moderate malocclusions, especially when buccolingual (tipping) movements of maxillary and mandibular incisors are involved. However, despite recent advances in treatment modalities using clear aligners, doubts still linger regarding the predictability of results. Consequently, further research is needed to explore their extended potential [22].

Mild to moderate crowding treated with IPR

Interproximal Reduction (IPR) is a method of gaining space by stripping enamel from tooth surfaces in a pre-determined manner. It plays a crucial role in clear aligner therapy, as it is necessary for the proper fitting of aligners and the execution of planned tooth movements. In cases of mild and moderate crowding, it is considered one of the potential ways to create space [23].

Although the success of clear aligners in treating crowding has been widely discussed, a study comparing the virtual arch form and the actual arch form post-treatment with clear aligners in terms of crowding resolution found the results to be dissimilar. Furthermore, the study revealed that the predictability of crowding relief was 87% in the upper arch and 81% in the lower arch. It also highlighted that IPR, being subject to the operator's skills, was shown to be an inefficient method for gaining space to relieve crowding [24].

Mild to moderate crowding corrected with arch expansion

Arch expansion is an effective method to alleviate crowding when there is a discrepancy between arch length and tooth material. The practice of arch expansion using clear aligner therapy has been examined in various studies. Yanqi Zhang et al. [25] investigated the effects of arch expansion with clear aligners, focusing on the unintended consequence of buccal flare in posterior teeth. This study emphasized the necessity of applying an appropriate torque compensation angle, considering the patient's current status and compliance, to counteract buccal tipping of the posterior teeth [25].

Another study concluded that controlled arch expansion requires prescribed torque movements in the aligners to achieve the desired expansion and to minimize anchorage loss [26]. Additionally, a comparison of arch expansion through clear aligners in different planes revealed that transverse arch expansion predictability was between 59%-83% in the upper arch and 49%-67% in the lower arch, decreasing from molars to canines in both arches. In the sagittal plane, predictability remained less consistent [24].

A further study analyzed 15 patients, aged 8-11 years, from January 2020 to December 2021, to examine maxillary and mandibular arch expansion associated with clear aligner therapy. A 3D digital oral scanner was used to create a digital model for monitoring progress before and after treatment. It was found that arch expansion was most effective in the maxillary canine region and least effective in the maxillary first molar region. The study suggested that the efficiency of aligners in arch expansion could be enhanced by implementing attachments and desired torque to control tooth movements [27].

Treatment Challenges and Solutions

Severe rotations

Rotations may or may not be corrected with aligners, but they are undoubtedly considered to be among the most difficult movements to achieve, with a greater chance of relapse. As theorized by S. Jay Bowman et al [28], in 'Creative Adjuncts for Clear Aligners Part 2: Intrusion, Rotation, and Extrusion,' dental rotations are seen as the least predictable aligner movements [28]. Vincenzo D'Antò et al [29], in their study, pointed out that conically shaped teeth, such as premolars and canines, are difficult to derotate. They noted a further need for IPR (Interproximal Reduction) and attachments to accomplish this. The study also examined molar derotation in Class II malocclusion using CAT (Clear Aligner Therapy), finding that the derotation accuracy for the first molar was 77.5% and for the second molar 62.7% [29].

Treatment with CAT in early years

Clear aligners are primarily indicated for adults, as all teeth have erupted, and clinicians do not have to worry about ongoing growth that could alter results during the course of treatment. However, Waddah Sabouni et al [30] explored the use of clear aligner therapy in treating early transverse malocclusions, as well as Class II and Class III malocclusions. Their research outlines various options for early orthodontics and the late mixed dentition phase. While it is possible to treat such cases with clear aligners, there is a lack of evidence to fully support this concept. One disadvantage of using clear aligners as phase one therapy is that the appliance must have a retentive fit. However, when many teeth are exfoliating and new teeth are erupting, achieving this fit becomes almost impossible, potentially compromising the outcome [30].

Treatment with impacted teeth

In one of the studies included in this literature review, the case of an impacted maxillary canine was examined. The 'Canine First' approach was employed, which initially involved invasively exposing the canine and then dragging it down into the arch. Subsequently, a clear aligner was used to move the canine mesially into the space of the missing lateral incisor to close the gap, followed by enameloplasty of the tooth crown. Occlusal refinement was then performed. The study highlighted the merits of aligners as being aesthetic, convenient, and an effective means of applying force to achieve the desired tooth movements, successfully aligning the impacted canine with the arch [31].

Premolar extraction case

The most common tooth extracted for orthodontic purposes is a premolar. Conventionally, CAT (Clear Aligner Therapy) was not considered a suitable treatment regimen for extraction cases, as they were regarded as more complex. However, with the introduction of modifications and attachments, CAT is now being used in such cases. One study presented a case that involved asymmetric extractions in both arches, including premolars and a compromised molar. Clear aligners successfully treated dental crowding and protrusion in a middle-aged patient. However, it was concluded that extraction cases like this require careful planning to overcome undesired movements, such as posterior teeth crowns tipping distally and canine crowns tipping mesially, and there should be extra control over the anterior teeth's torque [13].

Non-extraction cases have been successfully treated with CAT, and recent advances in technology have extended their use to extraction cases. For instance, one study titled 'Relative Anchorage Loss under Reciprocal Anchorage in Mandibular Premolar Extraction Cases Treated with Clear Aligners' confirmed the use of CAT in premolar extraction cases. It further compared the anchorage loss when extracting the first and second premolars. The study suggested that evaluating relative anchorage loss is crucial in planning CAT cases [32].

Molar distalization

Molar distalization has always been a challenging case for CAT (Clear Aligner Therapy), but recent literature does not dismiss its possibility. The efficacy of CAT has improved, making it a part of the treatment plan for Class II malocclusion, where maxillary molar distalization is required. Molar distalization serves as a valid alternative to non-extraction treatment for Class II malocclusion, as it reduces maxillary molar extrusion and provides better occlusal and vertical control [33]. Vincenzo D'Antò et al. [29] concluded in their study that CAT is a viable alternative approach for the distalization of molars. It was found to be successful in achieving 2 to 3mm of molar movement without losing control. The study observed an overall accuracy of 69.3% for the first molar and 75.2% for the second molar, with the help of refinements and attachments [29]. Another study stated that mandibular molars could also be translated with CAT and mini-implants when the correction is 2mm or more in the sagittal plane [34]. There is often some discrepancy between expected and actual results, especially when anterior retraction is also involved, as demonstrated by a study specifically focused on the efficacy of CAT in molar distalization with and without anterior teeth retraction. Additionally, this study showed an increase in arch width in the posterior teeth region due to dental arch expansion [35].

Patient-Centric Factors in CAT Success

Long-term treatment stability

Many patients favor CAT (Clear Aligner Therapy) as they perceive it to be the most socially acceptable management strategy for their orthodontic issues. However, they often have limited knowledge about the clinical factors underpinning this decision. Only a few studies have comprehensively addressed the detailed efficacy of clear aligners, with the majority still striving to establish a firm conclusion. This review aims to delineate some of the key determinants in the long-term stability of CAT and to explain how each factor contributes to the reliability of the appliance over time.

Orthodontic case selection

To achieve the treatment goals with CAT and to ensure the long-term stability of the adjustments undertaken, it is essential to select the right case for it. Clear Aligners have been used for the treatment of less complicated malocclusions. Undoubtedly, in most complex cases conventional orthodontic treatment with braces is the unmatched option to date. As confirmed by the investigation comparing different perspectives about CAT in orthodontists and general dentists 45% of the orthodontists were reluctant to treat patients using clear aligners because of their limited efficacy in certain cases and 40% of general dentists were discouraged from doing so due to their inexperience. [36]

One systemic study conducted by Gibrael Rosini et al. reviewed certain research done in the past to state the efficacy and predictability of CAT to allow different orthodontic movements in non-growing patients. It was found that it is an effective clinical regimen when used for alignment and leveling of the arches, the intrusion of anterior teeth was found to be the same as with conventional fixed appliances. The complexity of tooth movements increased for CAT against anterior teeth extrusion and rotation and it did not prove to be beneficial for such tooth movements. [37]

Following the same approach, different studies were undertaken for this review to identify the case-to-case variation to learn about the true potential of CAT. Alissa F. Borda et al. studied the efficacy of CAT in comparison to fixed orthodontic braces for the treatment of mild malocclusion in teenage patients. Affirming the research, it was concluded that interproximal and occlusal contacts, the position of the marginal ridge, and the buccolingual inclination of the teeth, with CAT were analogous to fixed orthodontic therapy. The overall results for mild malocclusion were a great success for CAT. [8] Byron Chou et al. studied moderate to severe Class I and II malocclusions in adolescents; results were comparable for both Clear

Aligners and Fixed Orthodontic Appliances with the former being more efficient and taking less time to reach the finish point. [38]

Little evidence exists about moderate to severe cases being treated by Clear Aligner Treatment which has been discussed in this review and needs further evaluation so orthodontist selects the right fit for the treatment provision to safeguard the long-term stability of the cases that will most definitely benefit from it.

Patient Compliance

The predictability and long-term success of Clear Aligner Therapy (CAT) depend heavily on patient compliance. Existing literature specifies a minimum aligner wear time of 20 to 22 hours per day, amounting to an overall duration of up to 400 hours for each aligner. This extended wear time requires the patient's utmost commitment to ensure the desired outcome, as the aligner is removable and must be taken off during eating and drinking. The risk of distortion, misplacement, or loss is higher due to its clear shade. While younger patients might not be the ideal candidates for CAT, substantial research underscores patient compliance as a crucial factor in the long-term stability of the treatment. A non-compliant patient, even with a minor malocclusion, who fails to wear the appliance for the prescribed duration, does not adhere to appointment schedules, or neglects oral hygiene maintenance, will likely not achieve the desired results, irrespective of the simplicity of the case. Consequently, the overall efficacy of CAT may diminish, and long-term stability cannot be assured.

Patient's skeletal growth

Traditionally, Clear Aligner Therapy (CAT) is used by non-growing patients, but recent times have seen emerging, albeit weak, evidence of its application in growing individuals. This demographic appears more receptive to CAT compared to conventional orthodontic therapy. However, further investigation is required, as the application of CAT in growing patients remains uncertain. This is due to ongoing growth, which can affect predicted tooth movement and increase the chances of relapse. Nevertheless, a few studies have supported the use of CAT in mixed dentition, focusing more on the patient's acceptance of the treatment due to its lower discomfort and quicker solutions compared to braces, rather than on detailed knowledge of treatment outcomes [39]. A comprehensive understanding of a patient's growth status and skeletal maturity indicators can be crucial in predicting treatment outcomes in advance. Proper case selection is key to ensuring long-term predictability of CAT in growing individuals.

Identification of Individual Variability

For an orthodontist, adopting the mindset that 'every case is a new case' is crucial when managing different patients. Given the biological and genetic uniqueness of each individual, a predictable outcome is not always guaranteed. However, it can be made more likely by considering the necessary prerequisites, thereby enhancing the chances of long-term success. Numerous studies have explored various variables; for example, the role of attachments has been widely studied, with findings indicating their positive impact on facilitating complex tooth movements. One study demonstrated a 70% efficacy in achieving maxillary transverse expansion without using any auxiliaries [40]. While many cases can be effectively treated with clear aligners alone, others, such as premolar extraction cases, may require combination therapy to achieve complex tooth movements like bodily movement, extrusion, root torquing, etc. [41]. This illustrates how case-to-case variation and a patient's adaptability can contribute to a successful outcome. Furthermore, a study investigated the impact of the polyurethane plastic used in clear aligners and its mechanical properties on the force exerted by the appliance. Over time, clear aligners undergo mechanical deterioration due to intraoral aging, resulting in a reduced force delivery and a diminished overall efficacy of the appliance. The attachments incorporated can exacerbate the surface deterioration of the aligner [42].

This underscores how individual variations can affect the course of treatment. For instance, a study noted that patients' unilateral chewing habits could lead to the loss of attachments from clear aligners [43], exemplifying individual variability. Therefore, it is essential for orthodontists to meticulously analyze each case and promptly address any drawbacks to align them with the treatment objectives, ultimately providing an outcome that endures.

Long-term Stability and Retention Strategies

Anchorage planning

Are clear aligners reliable substitutes for fixed orthodontic therapy? Given the inadvertent need for torque to elicit complex tooth movements and anchorage planning [44], the answer is neither straightforward theoretically nor practically. Anchorage planning is crucial for stability and resistance to unwanted movements of the anchor unit. In contrast, anchorage planning in fixed appliances is quite successful due to their metallic construction and firm adhesion. However, clear aligners, being removable entities made of thin plastic material, invariably require auxiliaries for anchorage planning and to prevent undue tooth movements. A study focusing on the use of attachments and advancements in aligner materials indicated that these measures have not completely resolved the issue, and anchorage loss remains a problem in the

long run with CAT [44]. Xulin Liu et al. [45] examined the use of Class II elastics in maxillary molar distalization using CAT. Their research successfully demonstrated the role of Class II elastics in reinforcing anchorage by limiting maxillary incisor proclination and maxillary canine extrusion [45]. Therefore, careful anchorage planning with clear aligner therapy can signify a change in the course of treatment and ensure long-term stability.

Retention phase

The long-term stability of orthodontic treatment is determined by the type of tooth movement, the shift induced, the duration of active treatment, and the post-treatment retention regimen. The retention phase is crucial for preserving the changes made during active treatment, as teeth have a tendency to revert to their original position. Relapse can occur due to the violation of the neutral zone. It's important to note that mandibular arches are less stable than maxillary arches, so their expansion should be carefully planned. Additionally, continual growth changes in the inter-canine width due to aging can contribute to instability [46].

The importance of adherence to the retention phase by patients is critical for long-term efficacy and overall clinical success. Various studies have aimed to differentiate the relapse occurring from Fixed Appliance Treatment (FAT) and Clear Aligner Therapy (CAT). It has been theorized that relapse is more common in treatments with clear aligners than with fixed appliance therapy following active treatment and a specific retention period. Graf et al. [47] investigated the impact of retention on treatment outcomes with a clear aligner over a period of 10 months. In their study, the mandibular arch was fitted with a bonded lingual retainer from canine to canine, and a removable Hawley's retainer was used in the maxillary arch. The study concluded that the retention and stability of achieved tooth movements were maintained 10 months post-retention. Graf also pointed out the risks of overcorrection and exceeding physiological boundaries, which can alter natural arch forms and make changes less stable in the long run [47], highlighting the need for strict adherence to retention protocols, which may not always be favored by patients. The frequent incidence of relapse after CAT underlines the importance for patients to follow the protocol and for orthodontists to meticulously plan both complicated and less complicated cases, as well as the post-treatment retention phase. This ensures the time, effort, and money spent on CAT are worthwhile. Alongside routine retention appliances and devices used in clinics, minor operational procedures such as Interproximal Reduction (IPR) and high cusps for correct interdigitation in buccal segments, which are beneficial in all three dimensions (sagittal, transverse, and vertical), can also be incorporated for final occlusal adjustments, leading to more stable outcomes [46].

Orthodontic Expertise and Treatment Planning

Orthodontist's Role and Decision-Making

The ability of orthodontists to establish a definitive diagnosis and proceed with an accurate treatment plan for Clear Aligner Therapy (CAT) is crucial, as it directly impacts the success and long-term stability of the case. The importance of precise case planning for achieving desired outcomes and its relation to the long-term efficacy of CAT is exemplified in a study by Julia Meri Smith et al. [48]. This study focused on a case of lower incisor tipping using CAT. In the crowded anterior mandibular region, there is often a need for root uprighting. Initially, the root movement was less than predicted, but with the orthodontist's timely decision to incorporate vertical rectangular attachments into the appliance for greater root movements, the outcome became predictable [48]. This review has highlighted the inclusion of attachments and auxiliaries in CAT to extend its capabilities. Expertise in planning and applying these attachments is essential. Letizia Perillo et al. [36] concluded in their study 'Clear Aligner Treatment: Different Perspectives between Orthodontists and General Dentists' that orthodontists have more experience with clear aligners than general dentists [36]. Another study corroborated that orthodontists tend to use auxiliaries and supplemental techniques in CAT more frequently than general dentists [49]. Waddah Sabouni et al. [50] showcased a complex case involving a 25-year-old female patient with a Class I skeletal relationship, bilateral Class II dental relationship, increased overjet, deep bite, and crowded maxillary and mandibular arches. This case was considered among the most challenging to treat according to available literature. However, the study concluded that appropriate attachment selection was an effective means of treating such cases [50]. The expertise demonstrated in this study, particularly in the judicious selection and application of attachments, is highly appreciated and serves as a testament to the skillful and innovative approaches required in advanced orthodontic treatments like CAT. Moreover, the expertise of orthodontists in carefully selecting cases, coupled with a step-by-step approach to molar distalization, precise anchorage planning, and the use of Class II elastics, confirms the long-term stability of CAT in complex cases. As advancements continue, the scope of CAT broadens.

Treatment monitoring and follow-up

The orthodontist's expertise is crucial in pre-treatment, mid-treatment, and post-treatment decision-making. Situations often deviate from the planned course of treatment, requiring the orthodontist to make timely and accurate decisions to ensure successful outcomes in cases selected for Clear Aligner Therapy (CAT). The randomized clinical trial by Mays Al-Nadawi et al. [51] exemplifies the importance of follow-ups

and adjustments to the original plan. They studied the effects of different CAT wear protocols on treatment outcomes at 7-day, 10-day, and 14-day intervals. The study found that all linear discrepancies were insignificant (<0.5mm), but angular discrepancies remained significant (> 2.0 degrees). Comparable accuracy was observed between the 7 and 14-day protocols, favoring shorter treatment durations. However, it was noted that posterior movements such as torque, tipping, and rotation required a longer 14-day duration. Mid-treatment follow-ups and routine examinations to predict different regimens positively impact the long-term stability of CAT [51]. Regular follow-up visits are essential to predict favorable outcomes, allowing monitoring of developments in the case and early intervention for any complications. This approach saves time and enhances efficiency in the long run. When planning a case, orthodontists must anticipate changes at the core of the problem. Recent innovations have facilitated this, proving beneficial for planning and monitoring cases. A study comparing software-predicted outcomes with actual clinical outcomes from aligner stages T0 to T4, T0 to T6, and T0 to T8 showed significant variations, with T4 accounting for 62% accuracy, T6 for 68%, and T8 for 78% in correction. This concluded that CAT was effective against mild to moderate malocclusion, but the success rate could be improved beyond what was predicted by proprietary software models [52]. Another study investigated serial digital scans for orthodontic tooth movements to record results consistently. Cases involving root movements in CAT are gaining attention for two reasons: first, the occlusion is ultimately influenced by root tipping; second, this affects the final fit of the aligner. If not as planned, the aligner's mechanical properties risk influencing the biomechanics of the appliance, leading to uncertain long-term stability [48]. Bochun Mao et al. [53] conducted a study on simulated tooth movements in molar distalization cases, examining the effect of maxillary molar distalization with clear aligners using Finite Element Methods (FEM) models of maxillary dentition, attachments, periodontal ligaments, and the specified aligner morphology. The study during the staged distalization process noted anterior teeth proclination and distal tilting of the second molar [53].

The growing popularity of innovations and software development has simplified predicting clinical outcomes, enabling the identification of adverse occurrences and risk factors earlier to ensure a sustained treatment regimen

Material Science in Clear Aligners

Aligner Material

An ideal aligner material possesses low hardness, high resilience, adequate elasticity, resistance to warpage, good biocompatibility, and optimal transparency. The advancements in materials for CAT, ranging from single entities or a blend of different materials to the incorporation of shape memory polymers, 3D printed materials, and bioactive materials, have enhanced the potency and long-term stability of clear aligners [54].

The thin plastic material used in fabricating aligners should have an appropriate level of stiffness, neither too high nor too low, to facilitate the intended tooth movement. Excessively stiff aligners can pose challenges in placement and removal, while those with insufficient stiffness may not exert the necessary force for desired movements. Additionally, the viscoelastic nature of the plastic aids in absorbing various forces, enabling the aligner to effectively deliver these forces to the teeth. However, the transparency of the material can be compromised due to wear from eating and drinking, affecting the aesthetic appeal of the aligners [54].

Deviations from the ideal and optimal material properties can disrupt the normal functioning of clear aligners, leading to a compromise in the long-term stability of the treatment. Consequently, achieving predictable results becomes more challenging.

Conclusions

Clear Aligner Therapy (CAT) has established itself as a prevalent choice in contemporary orthodontics, particularly for mild to moderate malocclusions. This narrative review underlines that while CAT shows promising results in these cases, it is also progressively addressing more complex scenarios and challenging tooth movements. Key determinants of long-term treatment stability, such as patient compliance and professional orthodontic expertise, are critical. An orthodontist's adeptness in case selection, meticulous planning, utilization of advanced technologies and software, individualized patient monitoring, and effective execution of retention protocols are instrumental in achieving sustained success with CAT. Furthermore, a thorough understanding of aligner material properties significantly contributes to treatment efficacy. There is a pressing need for ongoing research to expand our understanding of CAT's capabilities and limitations, which will enhance its application scope and optimize outcomes in diverse orthodontic scenarios.

Additional Information

Disclosures

Conflicts of interest: In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

References

1. Acar YB, Kovan A, Ateş M, et al.: How Efficient Are Clear Aligners? Clear Aligners vs Traditional Orthodontic Treatment: A Systematic Review. *Turk J Orthod.* 2014, 27:106-110. [10.13076/TJO-D-14-00016](#)
2. Jaber ST, Hajeer MY, Sultan K.: Treatment Effectiveness of Clear Aligners in Correcting Complicated and Severe Malocclusion Cases Compared to Fixed Orthodontic Appliances: A Systematic Review. *Cureus.* 2023, 15:38311. [10.7759/cureus.38311](#)
3. Loli D: Clear Aligners: strenghts and weaknesses. *WebmedCentral ORTHODONTICS.* 2017, 8:005407.
4. Kesling HD: The Philosophy of the Tooth Positioning Appliance. *Am J Orthod Oral Surg.* 1945, 31:297-304. [10.1016/0096-6347\(45\)90101-3](#)
5. Shetty SK, Wilson C, Kumar YM, et al.: Orthodontic Treatment with Clear Aligners. *Scholars J Dent Sci.* 2021, 8:230-233. [10.36547/sjds.2021.v08i07.008](#)
6. Ke Y, Zhu Y, Zhu M: A Comparison of Treatment Effectiveness Between Clear Aligner and Fixed Appliance Therapies. *BMC Oral Health.* 2019, 19:24. [10.1186/s12903-018-0695-z](#)
7. Jiang Q, Li J, Mei L, Du J, Levrini L, Abbate GM, Li H: Periodontal Health During Orthodontic Treatment with Clear Aligners and Fixed Appliances: A Meta-Analysis. *J Am Dent Assoc.* 2018, 149:712-720. [10.1016/j.adaj.2018.04.010](#)
8. Borda AF, Garfinkle JS, Covell DA, Wang M, Doyle L, Sedgley CM: Outcome Assessment of Orthodontic Clear Aligner vs Fixed Appliance Treatment in a Teenage Population with Mild Malocclusions. *Angle Orthod.* 2020, 90:485-490. [10.2319/122919-844.1](#)
9. Tamer İ, Öztaş E, Marşan G: Orthodontic Treatment with Clear Aligners and The Scientific Reality Behind Their Marketing: A Literature Review. *Turk J Orthod.* 2019, 32:241-246. [10.5152/TurkJOrthod.2019.18083](#)
10. Mehta S, Mehta F.: Aligners: the rapidly growing trend in orthodontics around the world. *IJBAMR.* 2014, 3:402-409.
11. Proffit WR, Fields H, Larson B, et al.: *Contemporary Orthodontics.* Elsevier, philadelphia; 2018.
12. Lin CL, Wang YC, Hsieh YJ, et al.: Clinical Effectiveness of Using Clear Aligners in Orthodontic Treatment. *Taiwanese J Orthodontics.* 2020, 32:2. [10.38209/2708-2636.100](#)
13. Xing X, Qin H, Sun J, Li K.: Asymmetric Extraction Treatment in a Middle-Aged Patient with Dental Crowding and Protrusion using Clear Aligners. *Case Rep Dent.* 2023, 2023:8836409. [10.1155/2023/8836409](#)
14. Tripathi T, Singh N, Rai P, et al.: A Modified Clear Aligner. *Int J Orthod Milwaukee.* 2016, 27:29-31.
15. El-Bialy T.: The Use of High Frequency Vibration and Clear Aligners in Management of an Adult Patient with Class III Skeletal Malocclusion with Open Bite and Severe Bimaxillary Protrusion: Case Report. *Dent J.* 2020, 8:75. [10.3390/dj8030075](#)
16. Suh H, Garnett BS, Mahood K, et al.: Treatment of Anterior Open Bites Using Non-Extraction Clear Aligner Therapy in Adult Patients. *Korean J Orthod.* 2022, 52:210-219. [10.4041/kjod21.180](#)
17. Sabouni W, Venugopal A, Adel SM, et al.: Correction of Anterior Open Bite of Varying Severity Using Clear Aligner Therapy-A Case Series. *Clin Case Rep.* 2022, 10:6277. [10.1002/ccr3.6277](#)
18. Pasciuti E, Coloccia G, Inchingolo AD, et al.: Deep Bite Treatment with Aligners: A New Protocol. *Appl Sci.* 2022, 12:6709. [10.3390/app12136709](#)
19. Greco M, Rombolà A.: Precision Bite Ramps and Aligners: An Elective Choice for Deep Bite Treatment. *J Orthod.* 2022, 49:213-220. [10.1177/14653125211034180](#)
20. Kravitz ND, Moshiri M, Nicosi J, et al.: Mechanical considerations for deep-bite correction with aligners. *Semin Orthodontics.* 2020, 26:134-138. [10.1053/j.sodo.2020.06.010](#)
21. Liu Y, Hu W.: Force Changes Associated with Different Intrusion Strategies for Deep-Bite Correction by Clear Aligners. *Angle Orthod.* 2018, 88:771-778. [10.2319/121717-864.1](#)
22. Robertson L, Kaur H, Fagundes NCF, et al.: Effectiveness of Clear Aligner Therapy for Orthodontic Treatment: A Systematic Review. *Orthod Craniofac Res.* 2020, 23:133-142. [10.1111/ocr.12353](#)
23. Huang AT, Huang D.: Interproximal Reduction. *Controversies in Clear Aligner Therapy.* Springer, Cham; 2022. 1:89-100. [10.1007/978-3-030-92810-0_5](#)
24. Fiori A, Minervini G, Nucci L, et al.: Predictability of Crowding Resolution in Clear Aligner Treatment. *Prog Orthod.* 2022, 23:43. [10.1186/s40510-022-00438-z](#)
25. Zhang Y, Hui S, Gui L, et al.: Effects of Upper Arch Expansion Using Clear Aligners on Different Stride and Torque: A Three-Dimensional Finite Element Analysis. *BMC Oral Health.* 2023, 23:891. [10.1186/s12903-023-03655-y](#)
26. Yao S, Jiang W, Wang C, et al.: Improvements of Tooth Movement Efficiency and Torque Control in Expanding the Arch with Clear Aligners: A Finite Element Analysis. *Front Bioeng Biotechnol.* 2023, 11:1120535. [10.3389/fbioe.2023.1120535](#)
27. Sun P, Xin Y: Arch Expansion Efficiency of Clear Aligner on Patients with Mixed Dentition Using 3ship Digital Oral Scanner. *J Biomed Nanotechnol.* 2022, 18:2786-2793. [10.1166/jbn.2022.3473](#)
28. Bowman SJ, Celenza F, Sparaga J, et al.: Creative Adjuncts for Clear Aligners, Part 2: Intrusion, Rotation, and Extrusion. *J Clin Orthod.* 2015, 49:162-172.
29. D'Antò V, Valletta R, Ferretti R, et al.: Predictability of Maxillary Molar Distalization and Derotation with Clear Aligners: A Prospective Study. *Int J Environ Res Public Health.* 2023, 20:2941. [10.3390/ijerph20042941](#)
30. Sabouni W, Mansour M, Gandedkar NH.: Scope of clear aligner therapy (CAT) in Phase I (early) orthodontic treatment. *Semin Orthodontics.* 2023, 29:216-236. [10.1053/j.sodo.2023.05.008](#)
31. Bocchino T, Martina S, Sangiuolo C, et al.: Maxillary Impacted Canine and Upper Lateral Incisor Agensis Treatment with "Canine First Technique" and Clear Aligners: A Case Report. *Healthcare (Basel).* 2023,

- 11:2345. [10.3390/healthcare11162345](https://doi.org/10.3390/healthcare11162345)
32. Tang Z, Chen W, Mei L, et al.: Relative anchorage loss under reciprocal anchorage in mandibular premolar extraction cases treated with clear aligners. *Angle Orthod.* 2023, 93:375-381. [10.2319/102222-727.1](https://doi.org/10.2319/102222-727.1)
 33. Balboni A, Cretella Lombardo E, Balboni G, et al.: Vertical Effects of Distalization Protocol with Clear Aligners in Class II Patients: A Prospective Study. *Minerva Dent Oral Sci.* 2023, 72:291-297. [10.23736/S2724-6329.23.04783-6](https://doi.org/10.23736/S2724-6329.23.04783-6)
 34. Auladell A, De La Iglesia F, Quevedo O, et al.: The efficiency of molar distalization using clear aligners and mini-implants: Two clinical cases. *Int Orthodontics.* 2022, 20:100604. [10.1016/j.ortho.2021.100604](https://doi.org/10.1016/j.ortho.2021.100604)
 35. Li L, Guo R, Zhang L, et al.: Maxillary Molar Distalization with a 2-Week Clear Aligner Protocol in Patients with Class II Malocclusion: A Retrospective Study. *Am J Orthod Dentofacial Orthop.* 2023, 164:123-130. [10.1016/j.ajodo.2022.11.016](https://doi.org/10.1016/j.ajodo.2022.11.016)
 36. d'Apuzzo F, Perillo L, Carrico CK, et al.: Clear aligner treatment: different perspectives between orthodontists and general dentists. *Prog Orthod.* 2019, 11:20. [10.1186/s40510-019-0263-3](https://doi.org/10.1186/s40510-019-0263-3)
 37. Rossini G, Parrini S, Castroflorio T, et al.: Efficacy of Clear Aligners in Controlling Orthodontic Tooth Movement: A Systematic Review. *Angle Orthod.* 2015, 85:881-889. [10.2319/061614-436.1](https://doi.org/10.2319/061614-436.1)
 38. Chou B, Nickel JC, Choi D, et al.: Outcome Assessment of Orthodontic Clear Aligner vs Fixed Appliance Treatment in Adolescents with Moderate to Severe Malocclusions. *Angle Orthod.* 2023, 93:644-651. [10.2319/020923-94.1](https://doi.org/10.2319/020923-94.1)
 39. Staderini E, Patini R, Meuli S, et al.: Indication of Clear Aligners in the Early Treatment of Anterior Crossbite: A Case Series. *Dent Press J Orthod.* 2020, 25:33-43. [10.1590/2177-6709.25.4.033-043.oar](https://doi.org/10.1590/2177-6709.25.4.033-043.oar)
 40. Galluccio G, De Stefano AA, Horodyski M, et al.: Efficacy and Accuracy of Maxillary Arch Expansion with Clear Aligner Treatment. *Int J Environ Res Public Health.* 2023, 20:4654. [10.3390/ijerph20054654](https://doi.org/10.3390/ijerph20054654)
 41. Torres FC, Jóias RP, Cepera F, et al.: A Clinical Case Treated with Clear Aligners. *Int J Orthod Milwaukee.* 2011, 22:11-15.
 42. Perkelvald A: Are Clear Aligners Better than the Conventional Orthodontic Fixed Appliances? . *Sci J Lander Coll Arts Sci.* 2022, 2022:46-53.
 43. Yaosen C, Mohamed AM, Jinbo W, et al.: Risk Factors of Composite Attachment Loss in Orthodontic Patients during Orthodontic Clear Aligner Therapy: A Prospective Study. *BioMed Res Int.* 2021, 2021:6620377. [10.1155/2021/6620377](https://doi.org/10.1155/2021/6620377)
 44. Brezniak N, Wasserstein A, Protter N.: Clear aligner biomechanical limitations: anchorage and couple (torque) development. *Angle Orthod.* 2023, 93:615-6. [10.2319/1945-7103-93.5.615](https://doi.org/10.2319/1945-7103-93.5.615)
 45. Liu X, Cheng Y, Qin W, et al.: Effects of Upper-Molar Distalization Using Clear Aligners in Combination with Class II Elastics: A Three-Dimensional Finite Element Analysis. *BMC Oral Health.* 2022, 22:546. [10.1186/s12903-022-02526-2](https://doi.org/10.1186/s12903-022-02526-2)
 46. Kucera J, Marek I.: Chapter 19: Retention and Stability Following Aligner Therapy. . *Principles and Biomechanics of Aligner Treatment.* Kucera J, Marek I (ed): Elsevier, st.louis missouri 65043; 2021. 274:259-274.
 47. Graf I, Puppe C, Schwarze J, et al.: Evaluation of Effectiveness and Stability of Aligner Treatments Using the Peer Assessment Rating Index. *J Orofac Orthop.* 2021, 82:23-31. [10.1007/s00056-020-00249-z](https://doi.org/10.1007/s00056-020-00249-z)
 48. Smith JM, Weir T, Kaang A, et al.: Predictability of Lower Incisor Tip Using Clear Aligner Therapy . *Prog Orthod.* 2022, 23:37. [10.1186/s40510-022-00433-4](https://doi.org/10.1186/s40510-022-00433-4)
 49. Best AD, Shroff B, Carrico CK, et al.: Treatment Management Between Orthodontists and General Practitioners Performing Clear Aligner Therapy. *Angle Orthod.* 2017, 87:432-439. [10.2319/062616-500.1](https://doi.org/10.2319/062616-500.1)
 50. Sabouni W, Muthuswamy Pandian S, Vaid NR, et al.: Distalization using efficient attachment protocol in clear aligner therapy-A case report. *Clin Case Rep.* 2023, 11:6854. [10.1002/ccr3.6854](https://doi.org/10.1002/ccr3.6854)
 51. Al-Nadawi M, Kravitz ND, Hansa I, et al.: Effect of Clear Aligner Wear Protocol on the Efficacy of Tooth Movement. *Angle Orthod.* 2021, 91:157-165. [10.2319/071520-630.1](https://doi.org/10.2319/071520-630.1)
 52. Izhar A, Singh G, Goyal V, et al.: Comparative Assessment of Clinical and Predicted Treatment Outcomes of Clear Aligner Treatment: An in Vivo Study. *Turk J Orthod.* 2019, 32:229-235. [10.5152/TurkJOrthod.2019.19019](https://doi.org/10.5152/TurkJOrthod.2019.19019)
 53. Mao B, Tian Y, Xiao Y, et al.: The Effect of Maxillary Molar Distalization with Clear Aligner: A 4D Finite-Element Study with Staging Simulation. *Prog Orthod.* 2023, 24:16. [10.1186/s40510-023-00468-1](https://doi.org/10.1186/s40510-023-00468-1)
 54. Bichu YM, Alwafi A, Liu X, et al.: Advances in Orthodontic Clear Aligner Materials. *Bioact Mater.* 2022, 22:384-403. [10.1016/j.bioactmat.2022.10.006](https://doi.org/10.1016/j.bioactmat.2022.10.006)