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Review article

Clear Aligner System and Its Role in Tooth Movements During Orthodontic Treatments: A Narrative Review

Ferial Msallam[1]*, Salimah Himeer[2]

[1]*Department of Orthodontics, Faculty of Dentistry, University of Tripoli, Libya.*
[2]*Department of Orthodontics, Zliten Dental School, AL Asmarya Islamic University, Zliten, Libya.*
Corresponding email. *Feralmsalam@yahoo.com*

Abstract
Since most patients, especially adults, don't like the way fixed appliances look, clear aligner therapy (CAT) has drawn interest from both patients and physicians. Clear aligners bring unique therapeutic issues due to their distinct material features, biomechanical properties, and treatment efficiency. The clear aligner was first introduced as the Invisalign® system in 1997 by Align Technology© (Santa Clara, CA) 1997 which was produced by computer-aided design and computer-aided manufacturing (CAD-CAM). Simple tooth movement was initially treated by the Invisalign technology. But as technology advanced, the manufacturer started utilizing intermaxillary elastics and attachments to achieve various tooth motions, making Invisalign a competitive substitute for fixed appliances. In order to ensure the clinical success of CAT, this narrative review examined the indications and contraindications of CAT, as well as its effectiveness and limits, the CAT concept, and movement mechanics provided by various attachment types, clinical procedures, follow-up, and complication issues. In summary, CAT has undergone improvement throughout the past several years. Patient adherence, case selection, and the clinician's personal experience all affect the outcome of therapy. It is recommended that the patient be informed of the benefits and drawbacks of CAT by the practitioner, and they should only take the device off when eating.
Keywords. Clear Aligner System, Role in Tooth Movements, Orthodontic Treatments.

Introduction

Malocclusion is known as a dental occlusion abnormality that deviates beyond the range of what is considered normal in terms of tooth alignment and/or relationship (1). The estimated frequency of malocclusion in the general population ranges from 43.5% to 67.2% (1, 2). Malocclusion raises the possibility of certain oral disorders and aesthetic issues, which might negatively impact mental wellness and standard of living (3, 4).

Clear aligner therapy, a major advancement in contemporary orthodontics, provides a practical and aesthetically pleasing substitute for conventional Fixed Appliance Therapy (FAT) for mal-aligned teeth (5). Clear aligner therapy is a removable orthodontic technique that uses custom-made aligner appliances made from semi-elastic transparent thermoplastic to reposition the mal-aligned teeth (2,5,6). Patients have been using clear aligners more often in recent years because of their simplicity, comfort, and aesthetic appeal in maintaining good dental hygiene (6). Because of their improved occlusal performance and increased patient satisfaction rate, clear aligners are a better option than traditional metallic brackets (5,7).

The digitalization through the use of CAD-CAM, stereolithography (STL), and tooth-movement simulation software, such as ClinCheck® Pro software (Align Technology, Inc.), in combination with the incorporation of clear thermoplastic plastics revolutionized clear aligners' therapeutic approach (8).

Comprehensive data analysis and design tools have made it possible for aligners to firmly cover the tooth surface and exert a mild, constant force that can be tailored to the precise movement direction and distance of each individual tooth. It is possible to exactly calculate the ideal tooth movement sequence to guarantee that the tooth advances in the intended direction (9-12).

The initial application of clear aligner was limited to mild malocclusions and minor tooth discrepancies; braces continued to be beneficial against a wide range of tooth movements, such as root paralleling and torquing, and had a lower relapse rate, while clear aligners were thought to be helpful for partial tooth movements, resulting in quick case completion (8). Additionally, clinical indications have broadened from straightforward to intricate circumstances, including surgical scenarios, and clinical remedies have changed from adjusting the movement of individual teeth to adjusting the group of teeth (5,13,14).

However, because it is an innovative approach that differs from conventional fixed appliances, CAT poses new difficulties in case selection, treatment planning, aligner design, and follow-up tracking. These difficulties are linked to variations in material properties and characteristics as well as treatment results (10,12,15). In order to enhance treatment effectiveness and encourage the ongoing development and application of this clinical approach, it is necessary to have important clinical characteristics of CAT (2).

Clear aligner therapy has emerged as the main growing trend in orthodontics. Although the usefulness of CAT has distinct benefits and drawbacks, there are still a number of unanswered questions that require fully discussing the clear aligner's potential and broader application (2,6). Therefore, the goals of this narrative review are to cover the history, basic technology, and biomechanics of CAT and to provide

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practitioners with a summary of clinical advice about indications, treatment strategies, aligner design, and follow-up screening.

History of the aligner

Kesling created a thermoplastic tooth positioner to gradually reposition teeth into better positions, which led to the invention of clear aligners (16). Following that, an "invisible retainer" was invented, which works on the same concept as Kesling's device but only produces slight tooth movement (17). Sheridan suggested utilizing transparent aligners with interproximal reduction, which also causes little tooth movement and necessitates taking a fresh impression at nearly every appointment. As a result, this approach takes time in the lab and in the clinic (17,18).

The Invisalign® system was introduced by Align Technology© (Santa Clara, CA) in 1997. The business produced its orthodontic appliances using CAD-CAM. The clear aligner as we know it today was made possible by this technique, which enables many tooth motions from a single imprint (17). Simple tooth motions were initially treated with the Invisalign® technology. But as technology advanced, the manufacturer started utilizing intermaxillary elastics and attachments to achieve various motions, making Invisalign® a competitive substitute for fixed appliances (17, 19). Other Invisalign®-like aligner systems, such as ClearCorrect and ClearPath, have entered the market and work on the same concept to produce the intended effects (17).

Methods of clear aligner fabrication

Fabrication by vacuum-formed technology

The manual approach is a labor process, requiring manual repositioning of the teeth, wax setting, and production of vacuum-formed retainers (20, 21). This method makes it simple and affordable to fabricate aligners in laboratory settings. Additionally, it makes treatment follow-up easier and enables the orthodontist to make the required treatment adjustments sooner (20).

A working cast is created by taking full arch impressions employing polyvinyl siloxane (PVC) material. A 0.25-mm handsaw is used to cut off the teeth that are scheduled to be relocated in each aligner from the working castings (20). After the target teeth have been separated, they are positioned as desired and secured with block-out wax (21). The interproximal reduction is carried out at this point if necessary. Following this adjustment, a vacuum or pressure molding machine is used to mould plastic sheets onto the setup model. The patient receives a three-piece set of aligners after the last trimming treatments (20, 21).

Aligners come in three different thicknesses: 0.020, 0.025, and 0.030 inches. Increased control regarding tooth movement and less discomfort from orthodontic pressures are two benefits of using increasingly thicker aligners. Two or three aligners of different thicknesses are made from a single set of impressions, and the patient is told to wear each aligner for ten to fifteen days (20, 22). The clinician can adjust the treatment plan during treatment and track the advancement of the tooth movement since the aligners are made from a fresh working cast and acquired from a fresh imprint taken at every appointment (20).

Fabrication by CAD-CAM innovation

The profession and orthodontic appliances have been completely transformed by the use of digital technologies (23). The CAD-CAM systems are now used in orthodontics and aligner therapy, much like in other areas of dentistry. The most well-known aligner system, Invisalign®, has evolved into a brand name for other superior CAD-CAM technologies. The most advanced and widely utilized clear aligner innovation on the market right now is this system (22,23). The CAD-CAM innovation is used in the design and manufacturing of the aligners in the Invisalign® system. Invisalign®, is a leader in aligner therapy thanks to its mix of computerized virtual therapy design and manufacturing stereolithographic prototype technology (20, 23).

Materials for clear aligner fabrication

Removable aligners are made up of thermoplastic materials because of their simplicity to use, excellent aesthetic characteristics, and superior formability (24). Thermoplastic materials are polymers that are either in the linear or slightly branched configuration. Strong covalent and weak Van der Waals bonds hold the different units of the plastic together. On heating, the molecular chains move and make the plastic flexible and pliable to any desired shape, and subsequently, they cool down to room temperature. During cooling, the molecular chains solidify and retain their new shape (24, 25). Various thermoplastic materials that are currently used for fabrication include polyvinyl chloride, Polyurethane (PU), polyethylene terephthalate (PET), and polyethylene terephthalate glycol (PETG) (26).

Polyurethane (PU)

Polyurethane is primarily composed of di- and tri-isocyanates, and polyols also contain some additional materials to improve the properties of the plastic. Because of its characteristics, the material is frequently used in aligners (27). Polyurethane has a higher resistance to compression and tension, is harder, and has a higher load-bearing capacity, making it a popular material (28).

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Under loads, PU material changes its shape but later attains its original shape when the load is removed (26). The PU material can elongate and recover due to its flexibility. Additionally, the material has a broad range of resilience and great tear resistance. The use of polyurethane in invisible orthodontics is limited since it is often an opaque material whose opacity increases while mixing (27, 28).

Polyethylene terephthalate (PET)

The PET material is commonly known as polyester, which is made up of combining ethylene glycol with terephthalic acid. This material can be drawn into tapes, films, or fibers (27). The material of PET exists in both amorphous and crystalline forms, which influence the properties. (29). The amorphous structure of PET is transparent, whereas the crystalline structure is opaque and white (27). The crystalline forms of PET exhibit good strength, hardness, and stiffness, and the amorphous forms demonstrate superior ductility. The PET material can be either rigid or semi-rigid depending on the processing methods employed (27, 29). The material of PET displays excellent mechanical properties, toughness, and resistance against various solvents (29).

Polyethylene terephthalate glycol (PET-G)

Terephthalate Glycol is a non-crystalline copolyester, which is made up of 1,4-cyclohexane-2-methanol, ethylene glycol, and terephthalic acid. (27, 30) The PET-G material shows excellent transparency, adequate flow properties, and resistance against solvents. Polyethylene terephthalate glycol is the choice of material to fabricate complex and intricate designs. The PET-G materials are exceptionally durable, have high impact strength, and are resistant to chemical changes (31,32). Polyethylene terephthalate glycol is a transparent thermoplastic material and exhibits roughness that is lower than glass. Various bending tests suggested that PET-G is a very ductile material (27).

The PET-G is a modified and altered form of PET that transforms its form from semicrystalline to amorphous form making the material more transparent and aesthetically appealing (32). The glass transition temperature of the material is around 80 ℃, allowing better handling of the material with features that resemble glass. This modified PET also exhibits altered optical and mechanical properties (27, 31). The improved transparency, mechanical properties, and optical properties make PET-G a promising material in the fabrication of aligners (32).

Indications for CAT

Understanding the appliance's indications and determining which tooth motions are required to treat the clinical condition are key factors in the effectiveness of CAT (20). Even though it is well acknowledged that CAT is not the most effective option for treating every kind of orthodontic issue, as with fixed orthodontics, there is ongoing debate on the appropriate use of these aligners (2, 33). They can be utilized in more complicated orthodontic situations, according to some, while others advise using them in individuals with modest tooth crowding (34, 35).

Aligner therapy is typically indicated for mild crowding (1–5 mm), spacing issues (1–5 mm), deep overbites (Class II, division 2), narrow arches that need to be expanded, absolute intrusion (one or two teeth), severe crowding that requires lower incisor extraction, and molars that need distal tipping (17, 36, 37). Clear aligners are often recommended for use by adults or teenagers whose permanent teeth have fully erupted (38).

There is a substantial argument over whether moderate to severe orthodontic treatment can be performed habitually using an aligner (39). The inability to regulate root movement restricts aligner usage in malocclusions needing premolar extractions. This is regarded as one of the appliance’s most severe shortcomings (40, 41). Case studies including premolar extractions emphasize this issue since they indicated the need for permanent appliances to straighten the molars, premolars, and canines at the end of aligner therapy (41-43). In a previous case study of a successful clear aligner premolar extraction therapy, one advantage of using the clear aligner method was that it needed little bodily movement, simply small rotations, and no extrusion, intrusion, or torque movements (40).

Contraindications for CAT

The clear aligner is not recommended, however, for crowding or spacing issues greater than 5 mm, anteroposterior skeletal issues greater than 2 mm, centric relation and centric occlusion discrepancies, and severely rotated and severely tipped teeth greater than 45 degrees. Moreover, CAT is not recommended for cases requiring tooth extrusion, cases with open bite, or cases involving multiple missing teeth (44, 45).

Also, clear aligners are not advised for individuals who have clinically short crowns, need a lot of posterior tooth mesial movement, or exhibit poor compliance (33). Although using clear aligners to address some parts of malocclusion might be challenging, this does not indicate that it should be avoided completely because it can be used in conjunction with other therapies (40, 46).

Advantages of clear aligners

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The aligners are transparent, making them considerably more difficult to perceive than traditional wire and bracket orthodontics (16, 20). Because of this, the CAT is particularly well-liked by adults who want to straighten their teeth without looking like the conventional metal braces that kids and teens use so frequently (47). Additionally, CAT is easy to use with less chairside time needed (40).
Moreover, CAT facilitates dental hygiene with the benefits of better periodontal health and dental cleanliness (48). Clear aligners are the optimal treatment for adult orthodontic patients at jeopardy of periodontitis or those who have developmental defects in their enamel or are susceptible to dental cavities (2, 33). Unlike fixed appliance therapy, CAT appears to have no negative impact on gingival health throughout treatment (38). Moreover, in terms of function, emotional impact, and pain-related factors, it was found that clear aligners are more convenient than fixed appliances and have fewer negative effects on adult patients' lives (49). Orthodontic treatment with a clear aligner may result in the resorption of roots, with an average proportion of less than 10% of the initial root length, and its frequency is comparable to that of low orthodontic forces (50). According to a prior pilot study, patients treated with CAT had less root resorption than those treated with conventional fixed appliances (51).

Disadvantages of clear aligners
The entire treatment with CAT is expensive as compared to conventional treatment (52). Moreover, there is the possibility of misplacing the orthodontic aligner appliance (53). The orthodontist cannot change the appliance during treatment since the aligners are manufactured by the company from treatment start to treatment conclusion (20, 54). If the path of therapy veers off course, new impressions are needed, the case is restarted in the program, and the treatment begins over, which raises the cost (20, 47, 52). Though exceedingly rare, allergic and toxic responses to the orthodontic aligner material may occur (55).

Limitations of CAT
The CAT is mostly dependent on the patient's habits and consistency in wearing them because they are removable and do not always fix teeth (40). Additionally, it was found that lower premolars with round morphology might be challenging for aligners to grab and rotate (40, 56). Also, during space closure, aligners have a limited capacity to maintain teeth upright (19). Limited root movement control is also seen with clear aligners, such as root paralleling, general rotation correction, tooth uprighting, and tooth extrusion. Patient compliance is very important (20).
Furthermore, it was concluded that when orthodontists' proposal the CAT as the treatment plan, they must depend on their personal clinical experience (17). While its effects on anterior tooth extrusion, rounded tooth rotations, and anterior buccolingual inclination were unanticipated, clear aligner treatment was predicted in anterior incursion and for managing the posterior buccolingual inclination (52). Moreover, a great level of precision of anterior teeth buccolingual inclination by orthodontic aligner was also reported (57). However, an important part of a CAT plan involves the use of small buttons or attachments to help guide your teeth into their new position (20).

Complications of CAT
Tooth caries
White spot lesions (WSLs) or even caries might result from improper oral hygiene during CAT, which can upset the oral microbiome (58). However, individuals using transparent aligners have reduced levels of cariogenic germs, total bacterial plaque, and WSLs in their saliva when compared to patients receiving fixed orthodontic treatment (59, 60). This might be connected to the fact that transparent aligners have less of a negative impact on dental hygiene (2).

Periodontal injury
Periodontal damage is not a side effect of standard orthodontic procedures. On the other hand, orthodontic equipment can make it harder to maintain good oral hygiene, which would raise the risk of periodontitis and gingivitis. Clinical studies have demonstrated that clear aligners are better at preserving patients' periodontal health than fixed orthodontic products (61, 62).
Furthermore, by slowing down tooth movement, lowering aligner coverage, and extending the wear time between sets of aligners, design modifications might help reduce these hazards in patients with an inadequate periodontal state. For those who are prone to periodontitis and/or gingivitis, clear aligners are thus advised (2).
Alveolar bone defects, including fenestration and dehiscence, are another frequent side effect of orthodontic therapy (63). Nonextraction CAT was also linked to a higher prevalence of fenestration and dehiscence of alveolar bone (64). Therefore, the link between the root and the bone should be carefully addressed and analyzed, especially when designing an arch extension (2).

Root resorption
Root resorption might result from CAT. In contrast to those seen with fixed orthodontic treatment, it was claimed that CAT used a softer force, which led to a decrease the root resorption severity and rate (65, 66).

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Risk factors for root resorption include things like extraction, tooth position, root position (the cortical bone/root relationship) after treatment, and particular patterns of tooth movement (extrusion and/or intrusion). However, post-treatment root position has the strongest correlation with root resorption (67).
Restricting the mobility of roots inside the cancellous bone and preventing needless reciprocal movement are therefore important to lower the likelihood of root resorption. Additionally, the root-bone relationship is obvious in the digital design thanks to the software design with a root-bone system, which lowers the danger of root resorption (2).

Relapse

Relapse is common following orthodontic treatment due to insufficient remodeling of the muscle system and periodontal tissues. Relapse has been primarily associated in the literature with occlusal stability, tooth movement types, root-bone linkages, and the extraoral and intraoral muscle balance forces; the kind of orthodontic device employed has little bearing on the likelihood of relapse (2, 68). The best ways to lower the chance of recurrence are now thought to be using retainers and correcting oral hygiene issues (such as tongue-thrust swallowing, etc.) (2).

Clear aligners generations

In order to increase their effectiveness and treat different malocclusions in a more visually pleasing, comfortable, and efficient manner, the aligners have undergone several changes (69). The first or oldest type of aligners are thought to be first-generation aligners (70). The thermoformed polymers served as the only basis for the treatment's outcomes. It had no auxiliaries connected (27). However, second-generation aligners are manufactured along with the attachments to produce better tooth movement. The second-generation aligners also included composite buttons on the teeth and inter-maxillary elastics (27, 70). However, the invention of newer generations has been undertaken to achieve better results and treat a larger spectrum of malocclusions (27).
For treating class II and class III patients, the third-generation aligners included precision cuts, elastics, power ridges for the lower anterior and upper incisors, ideal rotation attachment for premolars, and a variety of canine attachments (71, 72). Fourth-generation aligners are the next smart-force generation, optimized root control attachments, a new multi-tooth approach for the open bite, and new optimized multi-plane movements are included in the fourth generation (70,73). However, fifth-generation aligners use bite ramps to provide a posterior gap, increased deep bite attachments on premolars for extrusion, and the pressure area to enable better intrusion (27,70).

Aligner attachments (Aligner buttons/power ridges)

Advanced aligner systems consist of aligners and attachments, just like braces systems consist of brackets and wires (72). Attachments (aligner buttons) are tooth-colored “white” small shapes that are fastened to the teeth throughout CAT (74). They are very effective for moving teeth, by acting as grips for the clear aligners to hold onto (56). Clear aligners tightly fit over the attachments, which helps hold them in place to slowly and gently move the teeth into their correct positions (75, 76).
The attachments are almost invisible and are made from a tooth-colored material, cemented to the surface of tooth, and removed after ending CAT (39). With or without the aligner trays in place, the attachments are typically hardly detectable, and most individuals choose to wear them even on important occasions (73).
Among the most influential tools established by Align Technology is SmartForce™ attachments (20). These small devices are like little anchors, adding grip and dexterity to clear aligners. The attachments give the orthodontist precision control and predictability in movement, so teeth straighten faster and more reliably (16). Attachments enhance the tooth's mobility by giving the aligner a surface to press against (77). Since the metal used in conventional braces is more rigid than the plastic employed in clear aligners, the materials' flexibility occasionally needs to be made up for in the places that need to shift (23).
Due to the round and smooth shape of teeth, attachments help move the teeth with precision in the correct direction to achieve the best result most efficiently in the shortest amount of time (71, 77). Attachments are often positioned in the middle of the tooth, which anchors the aligner to make it work very effectively (78). Sometimes, the attachment’s precise inwards, outwards, or rotation movement needs an attachment in an off-center location (79).
Some attachments are even “optimized” because their size, shape, and position are uniquely designed for each tooth by proprietary software (77). Also, the bubble in the aligner is designed to have an activation built into it. This bubble enables the aligner to put a three-dimensional (3-D) force on the attachment leading to very precise tooth movement (80, 81). Importantly, while some attachments are on a tooth to facilitate its movement, other attachments are used as anchors to move other teeth. This means teeth that you don't want to move, may have attachments to help in the movement of other teeth (77, 82).
Each attachment helps the aligners fit well and resist any tendency to slip, but some are more important than others (83). The poorly fitted aligner will typically get worse until the aligners need to be remade, greatly extending treatment time and compromising the quality of the result (20). Therefore, there has been a tendency to use increasingly more attachments (84). In addition, some types of tooth movement are more

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prone to aligner slippage than others. For example, rotating a tooth or bringing an upper incisor down are examples of movements that will not track without attachments. Without attachments, aligners on these teeth will slip (56).
Attachments can also be utilized to change the tooth's form and make their movement easier (77). Moreover, the aligner attachments can help when correcting a problem with a patient's bite or assisting with a complicated dental movement (85). In contrast, the attachments can also prevent unwanted movements in teeth that may naturally attempt to shift during treatment (86).

Size and shape of aligner attachments
A variety of sizes and shapes are available for clear aligner attachments, and the expert orthodontist can recommend the precise attachments for the treatment of specific cases (87). The aligner attachments are normally only about 1 to 3 mm in size and are the same color as the teeth enamel so they are hardly visible to the naked eye (76, 88).
The attachments' positioning and form are crucial because they are designed to provide the proper force to enable the tooth to rotate or move without unduly straining the roots (72). However, it was reported that attachment shape or size had little influence on the bodily movement of the tooth. A high modulus material utilized for aligner attachment may render them suitable for clinical applications (76).
The different attachment shapes are designed to enhance retention and facilitate complex orthodontic tooth movement (77, 87). Optimized attachment shapes are increasing in complexity and prove to be clinically better in controlling tooth movements (89). Depending on the goal of the tooth movement needed, the aligner attachments can be small rectangular shapes, triangular, circles, or squares (72).

Types of aligner attachments
Conventional attachments
Generally, the conventional aligner attachments are divided into three commonly used categories: ellipsoid, beveled, and rectangular (88). Sometimes they are angled or "beveled" in certain directions, completely intentionally (90).

Ellipsoid attachments
The ellipsoid attachments are used for retention or anchorage when the tooth surface area is limited, for example, for peg-shaped lateral incisors or the lingual surface of a lingually inclined mandibular second molar (91). Ellipsoid attachments are utilized individually for de-rotation or in pairs when trying root movements (71). More rotational mastery should be possible when ellipsoid attachments are utilized alone (92). However, when ellipsoid attachments are used in pairs, they should have the ability to produce moments of the couple to upright roots (40).

Rectangular attachments
The rectangular attachments are passive attachments that can be vertical or horizontal. They are positioned in the center of the dental crown by routine; however, they may be changed to any preferred position to help with the case's designed mechanics (93,94). The rectangular attachments are usually utilized when considerable mesiodistal motions are required (95). These rectangular attachments, it is supposed, will permit teeth to be physically moved by permitting a larger extent of the force application (96).
The horizontal rectangular attachments can be used for root control, particularly on the molars for labial root torque (72). These horizontal rectangular attachments can also be applied to short crowns to improve aligner retention (38,89). In unilateral crossbites, anchoring is provided by horizontal rectangular attachments on the non-crossbite side, which corrects the unilateral posterior crossbite on the contralateral side (97). However, when the program is unable to position the best root control attachments, such as mandibular incisors, in situations where one lower incisor needs to be extracted, the vertical rectangular attachments are utilized for root control (97).

Beveled attachment
Like fixed brackets, the beveled attachments contain an active border that should keep the aligner and teeth from moving (20, 40). Because it offers a flat surface for the aligner to press against in order to produce the appropriate tooth movement, the beveled surface is the active one (97). However, when attempting to extrude a tooth, beveled attachments are most commonly employed (40).
Beveled attachments can be beveled in both vertical and horizontal rectangular attachments (87). Horizontal attachments can be beveled to the occlusal or to the gingival to help with extrusion or intrusion movements. It is possible to employ a horizontal attachment beveled to the gingival for extrusive tooth motions on posterior molars. For intrusion, use the beveled horizontal attachment on the occlusal surface of the teeth next to the one that has to be pushed through. However, the vertical attachments can be beveled to mesial or to distal and used for rotation movements, for instance when correcting the first molar rotation (97).

Optimized attachments

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The optimized attachments have different characteristics from the conventional ones (89). These attachments consist of tiny composite bulges that are intended to create a force system that is advantageous for the intended movement (20). They are made to exert the ideal amount of force in order to provide a more consistent movement. They are tailor-made for each tooth's width, long axis, and contour. Moreover, they are precisely positioned to remove interferences and provide the pressures. The program defines each of these features, and the practitioner is not able to alter them (97).
Optimized attachments provide "Smart-Forces" put on the teeth (72). They supply the force required to produce the tooth's optimal mobility. Furthermore, they are automatically placed by the software when it detects certain thresholds of tooth movement. They are designed to control the force direction and point of application, and the amount of force applied. Every optimized attachment is customized to each individual tooth (72, 97).
Also, the optimized attachments have an active surface that contacts the aligner. Its active surface varies in geometry based on the unique morphology of each tooth (89). The aligner is designed at a more acute angle than the active surface on the attachment in order to exert a force on the active surface to move the tooth in the desired direction. As a result of this, the attachment size on the tooth will differ from the size of the space in the aligner for attachment (reservoirs). If an optimized attachment needs to be replaced midway through treatment, the clinician will need to use the attached template to re-bond the attachment, instead of using the last aligner (97).

Philosophies for CAT

Each case of CAT has a different level of treatment difficulties (2). Because clear aligners are composed of elastic materials, when they are positioned, the rebound force produced by the elastic deformations of the aligner materials moves teeth (6). As a result, aligners primarily offer a "pushing force," and the clinical effectiveness of these devices differs depending on the kind of tooth movement (2, 33). Accurately determining the level of treatment complexity and choosing the best instances are therefore essential (2).
In contrast to conventional fixed orthodontic equipment, clear aligners are composed of elastic materials that cover the entire or partial clinical crowns. This deformation of the materials produces a "pushing" force. Therefore, in theory, the force may be made to apply to any area of the tooth crowns on condition that the aligners are tightly covering it. The surface area of the crowns and the aligners' suitability are therefore crucial factors in successful treatment. The crowns are joined using attachments utilized in CAT, which can both expand the surface area and provide additional action points. Clear aligners can be supplemented with attachments of different sizes and shapes to meet varying biomechanical needs (2).
Furthermore, within a specific range, the elastic force of aligners is proportional directly to the degree of material deformation; however, excessive distortion could end up in plastic deformation, which would reduce the force. Furthermore, when the deformation duration increases, all of the elastic force diminishes (9). Consequently, a sequence of intermediate statuses is included in the design of clear aligners in order to connect the initial and ultimate statuses. When the aligners are changed on a regular basis, a constant, mild push helps the teeth progressively migrate into the ideal position (2).
Therefore, the three essentials for the effectiveness of CAT are the starting, middle, and finishing positions. Patients' features, particularly the digital dental models that depict the intraoral dentition and occlusion, are used to establish the starting position. The goal of intermediate positions is to guarantee that the tooth movement route and rate adhere to the biological and biomechanical orthodontic tooth movement principles. Perfect posterior interdigitations, anterior normal overjet or overbite, and well-aligned dental arches are required for the optimal ultimate position. Thus, in essence, CAT is a three-dimensional tooth repositioning procedure (2, 7, 98).

Biomechanics of the aligner /attachment system

Better outcomes might follow from more suitable patient selection and more precise treatment sequencing if the mechanics of tooth movement with aligners are understood (99). Tooth movement mechanisms by clear aligners can be described from two diverse standpoints: the displacement-driven system and the force-driven system (100).
Simple motions like tilting or slight rotations are primarily controlled by the displacement-driven mechanism. The tooth continues to travel until it aligns with the aligner, which is made based on the tooth's position in the subsequent staged location. It is well recognized that this mechanism is inadequate for generating root movements and less efficient at regulating tooth movement (20, 100).
However, the force-driven system needs biomechanical concepts to make tooth movement easier. The purpose of aligners is to exert the appropriate stresses on the teeth. The form of the tooth and the aligners that generate these pressures are not always the same (20). Specialized simulation software is used to establish the aligner form, the movement needed for each individual tooth, and the mechanical principles to achieve this movement. To apply the required forces, pressure points or power ridges are used to change the geometry of the aligner (99). While power ridges regulate torque and axial root movements, pressure points make uprighting and incursion motions more challenging (101).

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Procedures for aligner attachment application

The application of aligner attachment is simple, and most importantly, it doesn't hurt or cause the patient any discomfort (20). In the beginning, the orthodontist trims and removes excess template areas from the aligner template that do not include attachments or sections the template if there are multiple attachments in different quadrants (102). For example, if one of the arches has four attachments only on the upper incisors, remove the bicuspids and molars from the template with scissors (20, 103). However, if attachments are on the bicuspids, canines, and incisors, the molars may be removed from the aligner template, and the template may be sectioned at the midline and each quadrant bonded separately (102).

Once the aligners are ready to be fitted, the orthodontist will place a gel on the tooth surface where the attachment will go (104). The tooth must be clean and dry. After that the attachments are added to the inside of the aligner, the aligners are fitted, and then the orthodontist uses a curing light so that the material adheres correctly to the tooth. Then the aligner is removed carefully to see if the attachments have fixed to the surface of the tooth (103, 104). The patient may now use their aligners as the attachment has finally been installed in their tooth position (102).

Orthodontic tooth movements with CAT

Extrusion

Extrusion was shown to be the least precise method of tooth movement in a previous study that evaluated the efficacy of removable polyurethane aligners in a clinical trial (105). However, attachment development has increased extrusion efficiency. It is essential to have attachments with a flat, active surface that the aligner can exert force on (72, 106). Since the aligner interacts in the active region, this part of the connection is the most crucial. The rest of the attachment serves as a reinforcement and attachment (73).

The most popular attachments for extruding teeth are beveled ones, which are beveled towards the gingiva. Another way is to employ a power grip attached to the buccal surface of the extruded tooth, two aligner buttons at the surrounding teeth, and an elastic (107). Three to four times a day, the elastics are changed to start the extrusion process (108). The aligner holds the tooth in position once the required extrusion is complete (43). When 2 to 3 mm extrusions are required for open bites, intermaxillary elastics can be used (107). Elastics on the buttons of the extrusion teeth attach them to the opposing arch. The target teeth will be in contact with the inner surface of the aligner after the planned extrusion is finished, and no further extrusion will take place (40).

Intrusion

Applying the ideal intrusion force to the target teeth while maintaining the stability of the anchoring teeth is the best aligner treatment method for accomplishing intrusion in a shorter period of time (109). The benefit of the aligners is that they prevent posterior tooth extrusion by covering all of the teeth (40).

Composite attachments on the impacted teeth are typically not necessary (72). However, the anchor teeth should have horizontal rectangular attachments for anchoring and concomitant extrusion of these premolars (109). Placing two buttons on the aligner at the buccal and lingual gum levels of the target tooth is another extrusion strategy. In order to hook the elastics in the case of anterior tooth incursion, the incisal edge is then carved with two deep grooves (40).

Torque

Power-Ridges can be utilized to move aligners with torque (71, 110). They serve to provide a lingual or palatal force to the crown's cervical region, which, when constrained by the plastic material that covers the tooth's incisal edge, generates two forces, one of which is anticipated to result in the lingual torque (40, 110).

An effective combination of forces must be produced in order to regulate the torque of an upper central incisor (111). A tipping force is generated by the appliance's reversible deformation that follows the gingival line, and a consequent force is generated when the tooth moves against the appliance's opposite internal surface close to the incisal edge (40).

Rotations

Rotation may be accomplished in two ways. Firstly, a pair of forces can be generated to rotate a tooth by connecting attachments to the rotated tooth on the palatal and buccal surfaces and employing elastic links between them either before or during the CAT. The chains can be changed every three weeks until the rotation is fixed. Second, it is also possible to do canine and bicuspid rotations more predictably by employing better rotation attachments (40, 70, 112). Depending on how much effort is required to rotate the damaged tooth, they take on different shapes. An ideal attachment placed distal of the aligner allowed for mesiopalatal rotation correction as the aligner itself rotated (40).

Space closure

The teeth next to the extraction sites must have "root control" attachments in order to close the gap at the extraction sites (73, 96). Studies in the literature support the idea that proper utilization of these attachments can regulate root motions and provide positive outcomes (40).

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Molar distalization

Clear aligners can perform molar distalization with the maximum accuracy rate (71). The certainty of molar distalization with CAT is around 88%, according to clinical experience and literature (113). Attachments are not necessary to facilitate molar distalization. To improve the tooth with short crown grip, attachments are advised. Furthermore, attachments are typically necessary to increase the success rates of these movements and avoid off-tracking, as molar distalization frequently coexists with other intricate motions like intrusion and rotation. Conventional rectangular attachments are typically made for the canines to reduce the effect of precise cuts and improve aligner retention (114-116).

The anterior teeth may procline as a result of the counteracting force that clear aligners apply when they push to accomplish molar distalization through material deformation. Therefore, the anchoring of the anterior teeth should be strengthened if anterior tooth proclination is desired. In practice, intermaxillary elastics are frequently employed to accomplish this goal (117).

While buttons are attached to the buccal surface of the mandibular first molars (carved out on lower aligners) to enable the use of Class II intermaxillary elastics, precise incisions are made at the maxillary canines during maxillary molar distalization (118). A button can be attached to the labial surface of the canine close to the gingival border to aid with eruption if simultaneous eruption of the canine is desired (for example, low-positioned or inadequately erupted canines). Precision cuts at the mandibular molars are not advised, though, since they may cause aligner displacement or off-tracking (2).

Implant devices can also be utilized to strengthen the anchoring if needed, as long as they don't prevent the molars from distalizing (119). However, if anterior tooth proclination (such as Class II Division 2) is desired, it can be built concurrently with molar distalization, serving as a reciprocal anchoring to do away with the requirement for any elastics (120). However, for in-the-moment corrections, molar distalization and anterior proclination should be regularly observed during follow-up visits (2).

Arch expansion

To avoid buccal inclination, attachments must be made to the buccal surfaces of teeth during arch growth. In teeth, when the lingual cusps are not tall enough, lingual attachments can be positioned concurrently (121). For any extension that is more than 1 mm unilaterally, it is advised to create a phased expansion, such as molar distalization using a "V-pattern." It is proposed that because they might serve as reciprocal anchorages, identical teeth in the same jaw would expand at the same time. Clinicians can successfully integrate arch expansion into treatment programs for alignment with clear aligners by following these guidelines, guaranteeing the best possible results for patients with dental arch discrepancies (2).

Follow-up and treatment monitoring

Frequent follow-up appointments are crucial for educating patients on the difficulties and progress of their therapy, assisting them in understanding their roles in the process, and boosting their cooperation, compliance, and confidence (122, 123). Most people find it quite difficult to cooperate during the lengthy orthodontic treatment, particularly when it comes to continuing to wear clear aligners on a daily basis. As a result, being in regular contact with patients enables one to ascertain their condition and provide assistance or prompt reminders as required (2).

Comprehensive assessments should be conducted to determine the health of the teeth and periodontium, including mobility, the existence of premature contact, and occlusal damage, in order to gauge the effectiveness of therapy (124, 125). When compared to the baseline and digital design, occlusion alterations include the sagittal connection, occlusal contacts, inclination, midline of the upper and lower dental arch, overjet, overbite, torque, and space (2).

Any discomfort, soreness, or clicking in the joint area should be investigated during a temporomandibular joint health examination, particularly in patients with temporomandibular disorder before therapy and in adult patients wearing intermaxillary elastics (126, 127). In accordance with digital design, any attachment separation and/or abrasion should be examined (128). Assessments of aligner fitness take into consideration the advancement of tooth movement, particularly any gaps seen between the front teeth's incisal edges, the posterior teeth's cusps, the region around the attachments, and the aligner margin (2).

The limitation of the present narrative review includes the lack of comparison of the types, prices, and available CAT systems.

Conclusions

Over the past few years, CAT has been and continues to be enhanced. When a patient, particularly an adult, requests CAT, the practitioner should explain the benefits and drawbacks of the procedure. The patient should also be informed that the device should be worn all day and taken off just to eat. Patient adherence, case selection, and the clinician's personal experience all affect the course of treatment.

The effects of CAT therapy need to be assessed with precise follow-up. Clinicians should depend on their own expertise in addition to the few scientific information that is currently available regarding the indications and limits of CAT.

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