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Review Article
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Importance of Attachments in Treatment with Clear Aligners: A Narrative Review

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Objectives At present, clear aligners are widely used for treatment of complicated orthodontic cases such as severe crowding, and class II or III malocclusion. However, some movements such as extrusion, derotation, torque formation, or closing of large spaces are still challenging to perform with clear aligners. Resin attachments, elastics, some certain gingival margin designs, and thermo pliers have been suggested to increase the predictability of tooth movement with aligners. At present, it is well understood that attachments are a non-negligible part of treatment with aligners. Different experimental and clinical studies have assessed these features, but there is still no exact guideline for indications of each feature, or their effectiveness. Thus, the aim of this study was to review in vitro and clinical studies and to discuss the best approach to achieve more predictable tooth movement with clear aligners.

Methods Different databases including PubMed, Google Scholar and Scopus were searched and articles evaluating retention of aligners, different approaches to increase retention, and characteristics of attachments were included in this review.

Results Thirty nine experimental and clinical studies were included for this narrative review.

Conclusion The composition of aligner material probably plays a more important role than material thickness in retention. However, more comprehensive studies should be performed to confirm this. There is no doubt upon the necessity of using attachments to increase the retention of aligners and predictability of tooth movements. It seems that rectangular attachments are more efficient than ellipsoid ones. Also, quarter-sphere shaped attachments are preferred for rotational and root movements.

Keywords Composite Resins; Orthodontic Appliances, Removable; Review; Tooth Movement Techniques

Introduction

Numerous advances have been made in clear aligner treatments (CATs)from the introduction of positioners by Kesling in 1946[1] until the introduction of most advanced systems of Invisalign treatment by Align Technology (Santa Clara, CA, USA).[2] The Invisalign appliances include clear sequential aligners suitable for the increasing demand of patients especially adults for invisible orthodontic treatment.[3] The force system in aligners differs from that in fixed appliances, and the force required to move the tooth is obtained through the rebound force of the aligner.[4] In CAT, tooth crown is entirely covered by the appliance. Thus, the location of the applied forces and moments are not entirely obvious.[5]

CATs were initially limited to the treatment of mild crowding cases, but later, they were advanced to treat more complex malocclusion cases, such as extraction cases, open bites, deep bites, correction of class II and III malocclusions, and molar distalization cases.[6] Leveling and alignment, intrusion of anterior teeth, and upper molar distalization can be performed with the use of aligners with high predictability,[7, 8] but some other tooth movements such as extrusion of anterior teeth, correction of severe rotations, inclination of posterior teeth, torque formation, and closing of spaces larger than 5 mm are scarcely achieved by CATs.[9-11]

To overcome the limitations of these appliances and improve the predictability of tooth movement, auxiliary features such as resin attachments, thermopliers, and elastics as well as interproximal reductions were suggested.[4, 12] Attachments provide retention, but also facilitate complex tooth movements such as translation.[13] Now, it has been confirmed that use of attachments is an integral and necessary part of CATs.[14]

Many in vitro and clinical studies[7-12] have evaluated the predictability of tooth movements with aligners, the retention of aligners, and the efficacy of attachment application. But, to the best of the authors' knowledge, there is no conclusive review to choose the best approach in clinical field and to compare the results of different clinical and experimental studies. The aim of this review was to discuss different methods to increase the retention of aligners; thus, when clinicians want to treat different malocclusions, they would have more comprehensive knowledge about the recent advances in this context and can subsequently use the best approach to increase retention based on the type of malocclusion. Also, this review can be a comprehensive guide for the beginners for CATs.

Methods and Materials

In order to collect all the data from relevant clinical and

experimental studies, different databases including PubMed, Google Scholar and Scopus were searched for articles published from2000 to 2021, and articles evaluating the retention of aligners, different approaches to increase retention, and features of attachments (configuration, dimensions, location, and bonding protocols) were included in this review. Case reports and case series were excluded, and finally 39 studies were included in this narrative review. The findings of these studies are categorized as follows:

Results

Retention of aligners

One of the un quantified features of aligners is retention of them on the teeth. Despite the required flexibility for insertion and removal of aligners, rigidity and retention are crucial to induce tooth movement by them. Changes in material thickness and composition, and extension of the margins of the aligners and attachments have been recommended for better retention. However, there is no consensus upon the best approach.[15]

Contrary to common belief, thicker materials do not necessarily provide better retention, and material composition can play a more important role in this respect.[15, 16] However, the retention of different aligner materials has not been compared in vitro. A study by Al-Noor et al.[17] confirmed that materials with lower thickness can show higher retention, which may be attributed to their greater fitness or stiffness.

Another approach for retention improvement is insertion of attachments. Use of attachments should be considered with less retentive materials and light forces to prevent deflection of aligner while inducing greater tooth movements in order to prevent poor fitting.[17] Application of attachments with an ill-fitted aligner could not only decrease forces and moments, but may also cause movements in the opposite direction.[18]

Gingival margin design

One of the influential factors in retention of aligners is the form of gingival margin of the aligner. It can be scalloped or straight cut and it can be cut at the level of the gingival zenith or more apically.[19] Unfortunately, not enough studies have been done on this area, and limited evidence is available.

A study by Cowley showed that the most retentive design for gingival margin can be obtained by straight cut margin apical to the gingival zenith and the least retentive design is the scalloped margin combined with attachments. Thus, straight cut margin decreases the flexibility at the gingival regionand causes higher retention.[19]

Due to the thermoforming process of producing aligners, the material thickness decreases after thermoforming, especially next to gingival areas. This event subsequently causes easier deformation and increases thesusceptibility to fracture at the gingival margins.[20] Consequently, achieving torque movements would become more difficult due to higher flexibility at the location of force application.[21] A recent study[22] evaluated the thickness of aligners in different regions by micro computed tomography. They observed that the thickness of aligners was not homogenous at different sites; however, this difference in thickness was only significant at the molar region, showing lower thickness at the gingival region compared with the occlusal areas. This heterogeneity in thickness can justify lower predictability of some types of tooth movements with aligners.

Previously, Hilliard and Sheridan developed thermopliers to create dimples in aligners to improve fitness or modify the undercuts.[23] Also, Sheridan exerted composite mounds on teeth and created dimples within aligners to achieve greater tooth movements by localizing the force on specific are as of the tooth.[24] Thus, indentations inside the aligners can improve the considered moments and torque movements. But, no research has confirmed this phenomenon.[12] However, it has been shown that inserting indentations with thermopliers does not significantly increase the rotational control. It may even adversely cause intrusion during derotation. Also, it has been mentioned that sometimes indentations can cause further rotation instead of derotation.[25]

Configuration of attachments

Various configurations of attachments and their dimensions[15, 26], which have been mentioned in different clinical and experimental studies, are classified in Table 1.

Table 1- Classification of theconfigurations of attachments and their dimensions

Configuration	Width (mesiodistally)	Height (occlusogingivally)	Prominence (buccolingually)
Ellipsoid	2 mm	3 mm	0.75 or 1 mm
Vertical ellipsoid	2.5 mm	4 mm	2 mm
Rectangular	2 mm	3, 4 or 5 mm	0.5 or 1.0 mm
Beveled	2 mm	3, 4 or 5 mm	0.25 mm at beveled side and 1.25 mm at the opposite side
Pyramidal	3 mm	4 mm	1.5 mm
Quarter-sphere	1.5 mm (radius)	2.5 mm (diameter)	1.5 mm (radius)

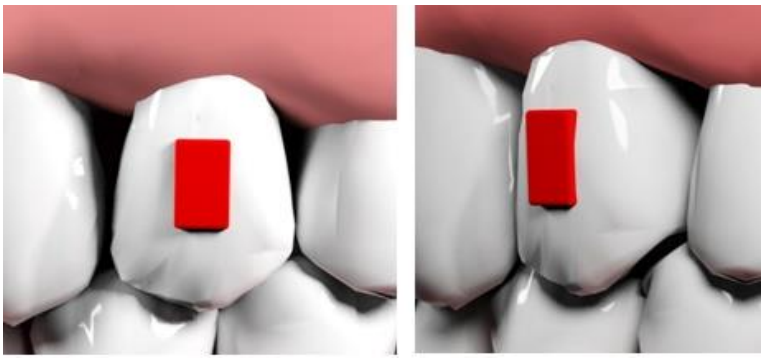
The mentioned attachments are illustrated in detail in Figures 1-5.

Dasy et al. showed that ellipsoid attachments would not increase the retention of aligners, and beveled attachments are better choices for this purpose.[15] Rectangular attachments are specified for large mesio-distal bodily tooth

movements and also provide larger area for force application.[12] Owen has shown improved extrusion and rotation movements and arch leveling by inserting horizontal rectangular attachments on buccal and lingual surfaces.[27] Beveled attachments have the same dimensions as rectangular attachments but they are horizontally beveled towards occlusal/ incisal or gingival, or vertically beveled towards mesial or distal.[15] These attachments are applied for extrusion and to prevent slipping.[12]

a b

Figure 1- Ellipsoid attachment on a maxillary first premolar: (a) labial aspect, (b) distal aspect



a b

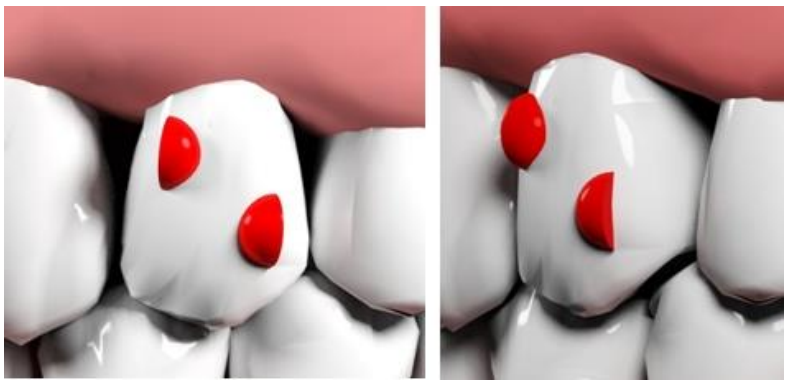
Figure 2- Rectangular attachment on a maxillary first premolar: (a) labial aspect, (b) distal aspect

a b

Figure 3- Beveled attachment on a maxillary first premolar: (a) labial aspect, (b) mesial aspect

a b

Figure 4- Pyramidal attachment on a maxillary first premolar: (a) labial aspect, (b) mesial aspect



a b

Figure 5- Quarter-sphere attachment on a maxillary first premolar:(a) labial aspect, (b) distal aspect

Elkholy et al. showed that quarter-sphere attachments are the preferred type for derotation of rotated mandibular canines. They can prevent intrusive forces while derotating. The active surface of these attachments is located at 120° relative to the surface of the tooth and 45° relative to the tooth axis. Also, they suggested considering these attachments even for small derotation movements of lower canines.[26]

Vertical rectangular attachments were first recommended by Align Technology for bodily distal movements. Afterwards, optimized attachments, which are mainly similar to quarter-sphere shaped attachments, were introduced to improve root control during distal movements.[28, 29] A finite element analysis (FEA) by Comba et al. indicated that canine distalization without attachment or with rectangular attachment would cause intrusion and distal crown tipping; while, insertion of optimized attachments would cause bodily translation although with some intrusion, which can be prevented by application of class II elastics directly to the attachment.[30]

Costa et al. (31)evaluated the effectiveness of three different attachments in producing extrusive forces. These attachments were the modifications of conventional ellipsoid, beveled and rectangular attachments, but with greater prominency and an inclined plane at the vestibular side to increase active surface. They concluded that shape of attachment can affect the intensity and direction of force and also, modified ellipsoid attachment, without edge and with less prominency, showed greater mechanical function even though it produced lower extrusive force than others.

Efficacy of attachments

FEA is one of the widely used methods in vitro to assess the efficacy of attachments. Yokoi et al. used FEA and demonstrated that attachments can control rotation and tipping of incisors while closing a diastema by bodily movement after sufficient time following the insertion of attachments.[32] Also, Gomez et al. reported the same results by FEA and confirmed the effectiveness of attachments for bodily movement.[33]

Another FEA study by Goto et al. showed that differences in shape and position of attachments do not influence forces and the amount of tipping movements during space closure.[5] Nonetheless, a recent FEA study by Kim et al. claimed that attachments would function more efficiently in tooth movement and torque control when they are placed at the lingual side rather than the labial side. Also, they recommended cylindrical attachments to obtain optimal contact area between the attachment and aligner and subsequently better stress distribution.[34] Another FEA by Chen Zhouyanet al.[35] compared the effectiveness of different locations and thicknesses of rectangular attachments for correcting the rotation of maxillary canine teeth. The results showed that movement of canine tooth and stress of periodontal ligament increase by greater thickness of rectangular attachment. Also, they confirmed the role of location of attachments in their effectiveness, such that occlusally placed attachments better control the rotation of canine tooth than apically placed attachments.

Extrusion of anterior teeth is a challenging movement to perform by the use of clear aligners. A previous study reported the lowest predictability for this movement.[36] A FEA study by Savignano et al. confirmed that extrusion of central incisors cannot be achieved without attachments. They suggested that the best approach for this movement would be the insertion of palatal rectangular attachments. Also, they emphasized the importance of the shape and position of attachments. The position of attachment is particularly important due to its effect on the active surface of attachment, which is planned for force delivery.[37] In agreement with their results, Cai et al. showed that the efficacy of attachments was predominantly determined by the direction of the active surface of attachment, which should be defined by the moment-force ratio of the planned tooth movement.[4]

In addition to experimental studies, a case-control study by Garino et al. exhibited the effectiveness of rectangular attachments on premolar and molar teeth for upper molar distalization with minimal distal tipping of the crown, molar extrusion or anchorage loss.[28] Also, a clinical study reported that buccal and lingual attachments didnot act better than buccal attachments alone for correction of rotations. But they emphasized on insertion of attachments for greater predictability.[38]

Despite the studies that favored the use of attachments, some other studies did not report better results with the use of attachments. Kravitz et al. declared that interproximal reduction and/or labial attachments with vertical ellipsoid shape would cause insignificant clinical improvement in correction of rotation of canine teeth compared with no use of attachments.[39]

Bonding protocols and composites used for attachments

As mentioned earlier, attachments are used for two main purposes: increasing the retention of aligners and supporting complicated movements. Considering the minimal size of optimized attachments, precise bonding of them is crucial. Given the fact that all aligners are produced based on the attachments, which are bonded thorough initial template, errors in initial bonding will result in unplanned tooth movements.[40]

Different bonding protocols have been suggested for insertion of attachments. Low viscous composite, high viscous composite, or a combination of them can be used to fill each attachment reservoir inside the template. Also, a perforation can be created in the reservoir to drain the excess composite. Weckmann et al. exhibited that producing attachments with high viscous composite via a two-phase procedure would result in minimum excess composite and is the most precise protocol. However, the protocol with high viscous composite without drainage will produce the least accurate attachments. Also, they claimed that perforations are only beneficial for use of flowable composites.[40]

Consistency and viscosity of composites can influence the position and shape of attachments, which are essential for attachment efficacy and aligner fitness.[37] It is important to effectively fill the reservoirs of the template during the bonding procedure. Narrow spaces can be finely filled with flowable composite although material molding is easier with packable composite. Flowable resin, orthodontic composite, and dental restorative composite have been compared for production of attachments. It was concluded that different composites do not affect the volume and shape of attachments and all of them are applicable for the fabrication of attachments.[13]

Also, Feinberg et al. compared the translucency, hardness, and stain resistance of restorative and orthodontic composites for attachment production. They observed that both of them would undergo staining over time. Also, orthodontic composite showed greater or similar hardness in comparison with the restorative composite. Thus, generally orthodontic adhesives as well as other composites can be utilized for attachment fabrication.[41]

In addition to precise bonding, it is essential to maintain the integrity and shape of the attachment during the treatment course. A clinical study by Barreda et al. compared the surface wear of nano-filled and micro-hybrid composites used for attachments during 6 months. None of them showed alterations in shape; however; micro-hybrid composite exhibited greater changes in the surface.[42]

Discussion

Some movements, such as torque formation and derotation are challenging to perform with the use of aligners.[10] Derotation of rotated mandibular premolars has particularly the lowest predictability due to their conical shape and lack of inter proximal undercuts, which conduces slipping of aligner during the derotation movement.[25]

To date, aligners have been consisted of three generations; the first generation solely relied on the aligners to achieve planned tooth movement, and no auxiliary feature was utilized. In the second generation, the manufacturers started to get help from the attachments by inserting composite buttons. Finally, in the third generation, the placement of attachments was programmed automatically by a software for complex movements such as root movements, extrusion and derotation. Also, indentations were inserted to improve root torque movements.[12]

Today, it is clearly understood that attachments are an inseparable part of CATs. Such attachments are first bonded passively via a template and they are not fully engaged after insertion of the first aligner. During the treatment and by constant utilization of aligner by the patient, the attachments progress the tooth movement and finally fit the aligner slot.[43]

A study by Momtaz et al. compared rotational movements by CATs without attachments, with attachments, and with insertion of indentations by Hu-Friedy clear aligner adjusting plier. Same as previous studies, they observed improved rotational movements with attachments. But, it is noticeable that increasing the number of attachments and insertion of indentations at the lingual side will result in hindering of the movement rather than improving it. It might be due to more thinning of the aligner while thermoforming with multiple attachments, and decreased fitness and inadequate engagement of the attachments after seating of the aligner.[25]

Another influential factor is the type of the material of the aligner. Nowadays, different thermoplastic materials such as polyester, polyurethane and polyethylene terephthalate glycol are utilized for the fabrication of aligners.[44] However, their difference in retention of aligners has not been evaluated yet. Material composition of aligners might affect retention more than their thickness.

Optimal consistency of composite attachments is important during CATs; otherwise, the teeth will not move desirably. Attachment loss can occur due to bond failure or patient incompliance.[15] A recent study by Yaosen et al.[45] evaluated risk factors leading to attachment loss and concluded that attachment loss is more prevalent in molar teeth, and wearing aligners less than 18h a day, unilateral mastication, and using tray seaters for aligners will lead to more attachment loss.Since these factors are patient-related, they can be prevented.

Conclusion

The greater thickness of the material is not necessarily equivalent to better retention of aligner. The material composition probably plays a more important role in retention. However, more comprehensive studies should be performed to confirm this, and comparison of the retention of different aligner materials is recommended.

Generally, nowadays there is no doubt upon the necessity of using attachments to increase the retention of aligners and predictability of different tooth movements.

The configuration of attachments should be chosen based on the type of tooth movement and retention requirements. It seems that rectangular attachments are more beneficial than ellipsoid attachments. Also, quarter-sphere shaped attachments are preferred for rotational and root movements.

Low- or high-viscous composites and also restorative or orthodontic types, are all applicable for attachment fabrication. Thus, orthodontic composites, which are available in every orthodontic office, can be easily utilized for this purpose.

More studies are required to decide on the best gingival margin design and also insertion of indentations by thermopliers in the gingival area for retention or specific tooth movements.

Conflict of Interest

No Conflict of Interest Declared■

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