ORIGINAL SCIENTIFIC ARTICLE

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The effect of attachment placement and location on rotational control of conical teeth using clear aligner therapy

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Key words *aligner, attachment, auxiliary, orthodontic, rotation*

Objective: *To determine the optimal method to correct rotations of conical teeth using thermoplastic appliances with and without attachments.*
Introduction: *Despite the increasing popularity of clear aligner therapy, there are still questions as to its effectiveness, efficiency, case selection and limitations. It has been reported that the full prescription for clear aligners is not expressed, and that the mean accuracy of any type of tooth movement using clear aligners is only 41% (Drake, 2012[13]). One of the major limitations of clear aligner therapy is the correction of rotated conical teeth, especially canines and premolars (Kravitz, 2008[14]). According to Simon et al (2014)[12], mandibular premolar derotation has the lowest predictability of movement and accuracy with clear aligners. This is due to the fact that conical teeth lack interproximal undercuts, and as a result, the aligner tends to slip as derotation is attempted (Kravitz, 2008; Simon, 2014). To address this limitation, the use of resin bonded attachments, interproximal reduction, overcorrection, auxiliaries, or adjusting aligners with thermopliers has been recommended – however the effectiveness of these methods has not been well established.*
Materials and methods: *The design of this in vitro study was prospective and experimental. A comparative study was performed to examine the effect of attachment location and the number of attachments on rotational control of conical teeth relative to control, which was rotational control with no attachments. Total rotation correction was recorded as an angular measurement after placement of each aligner, as measured on a digital scan (Ortho Insight 3D) using Geomagic Design software.*
Results: *Results of a one-way ANOVA showed that there were no statistically significant differences between the six groups. The group with a rectangular attachment on the buccal surface had the highest overall rotational correction.*
Conclusion: *Attachments appear to mildly improve rotational correction of the mandibular right second premolar. Increasing the number of attachments does not appear to aid rotational control, as the group with a single buccal attachment had the highest overall rotational correction. Multiple attachments, and adding attachments to adjacent teeth, appear to impede rotational correction in this study.*

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Introduction

As the number of adults seeking orthodontic treatment has increased in recent years, so too has the demand for aesthetic orthodontic treatment. The aesthetic treatment modalities available to patients and clinicians currently include ceramic brackets, lingual orthodontics and clear aligners. Clear aligner therapy is one of the fastest growing segments of the orthodontic market and is advantageous due the fact clear aligners are nearly invisible and are removable, thus allowing the patient to maintain better oral hygiene and reduce the risk of decalcification and caries often seen with traditional fixed appliances. Despite these advantages, little is understood about the effectiveness of clear aligner therapy, often leading to the need for case refinements, or mid-course corrections if aligners are no longer tracking. The decision must then be made to continue aligner therapy with revisions, discontinue aligner therapy with a compromised finish, or utilise fixed appliances.

In a study by Bollen in 2003[1], all patients who completed their first set of aligners required refinement or transition to fixed appliances to achieve the original pretreatment goals. Orthodontists typically report 70% to 80% of cases do not achieve pre-treatment goals and require further treatment[2,3]. One of the most common reasons for refinement or converting to fixed appliances is uncorrected rotations[2].

Although the use of clear aligners to correct alignment of teeth is a popular treatment choice for clinicians and patients, this treatment modality is not a new concept. H D Kesling first described the positioning of teeth without bands and wires with what he called a Tooth Positioning Appliance[4]. This tooth positioner would provide final finishing and artistic positioning of teeth, and could also be used as the final retainer. It was Kesling's vision that the tooth positioner be used for more than just final positioning and retention. He acknowledged that major tooth movements could be accomplished by sequentially repositioning teeth on the wax set-up and fabricating a series of positioners[4,5].

This vision was carried further by Henry I Nahoum, who described the vacuum-formed dental contour appliance in 1964[6]. Nahoum described a method where a plastic sheet is heated to moulding temperature and a vacuum formed over a dental cast. This differs from Kesling's tooth positioner in that maxillary and mandibular appliances are separate. This appliance can be used as a retainer after orthodontic treatment or fabricated to move teeth, similarly to the method Kesling described by re-setting teeth in wax on a model. According to Nahoum, anterior spaces and minor rotations can be corrected using this appliance, and corrections are limited to the six anterior teeth. In 2004, Sheridan et al[7] also described aligning teeth using a technique which included interproximal reduction of teeth and clear Essix aligners.

Since then, several companies have emerged, including Invisalign and Clear Correct. Invisalign was founded in 1997 and uses three-dimensional graphic imaging and computer-aided design/computer-aided modelling techniques to fabricate a series of aligners in order to achieve desired tooth movements[3,8,9,10]. These aligners are fabricated from thin, 0.030-inch thick plastic, which fits over the buccal, lingual (palatal) and occlusal surfaces of the teeth[3]. The aligners are to be worn a minimum of 20 h per day and advanced to the next aligner in the series every 2 weeks. Each aligner is designed to move teeth 0.25 mm to 0.3 mm[3,11]. To correct rotations, each aligner is designed to produce a 2 to 3 degree rotational change[12].

Despite the increasing popularity of clear aligner therapy, there are still questions as to its effectiveness, efficiency, case selection and limitations. Little is understood about the mechanism of action of aligners, force delivery, limitations and indications. It has been reported that the full prescription for clear aligners is not expressed, and that the mean accuracy of any type of tooth movement using clear aligners is only 41%[13]. One of the major limitations of clear aligner therapy is the correction of rotated conical teeth, in particular canines and premolars[14]. According to Simon et al[12], premolar derotation has the lowest predictability of movement and accuracy with clear aligners. This is due to the fact that conical teeth lack interproximal undercuts, and as a result the aligner tends to slip as derotation is attempted[12,14]. To assist derotation of round teeth, clinicians use resin-bonded attachments, interproximal reduction, overcorrection, auxiliaries, or adjust aligners with thermopliers in order to achieve the desired movement. The purpose of this study is to assess the efficiency of derotation of conical teeth using no attachments, and various attachment locations to assess the ideal location for placement of the attachment.

Material and methods

Fabrication of study models

Study models were fabricated using Type III blue stone (Henry Schein Dental, Melville, NY, USA) with missing mandibular right first premolar, mandibular right second premolar, and mandibular right first molar. Typodont teeth (Kilgore International, Coldwater, MI, USA) were placed on the model and embedded in base plate wax. The model was designed so that the mandibular right second premolar was rotated 30 degrees. An acrylic stent was fabricated and reinforced with laser-welded steel wire. This stent would allow for resetting teeth to their original positions.

Reference points were placed distal to the mandibular right second molar and at the cusp tip of the mandibular left canine. A reference line was also placed along the occlusal surface of the mandibular right second premolar. These references would serve as markers to allow measurement of rotational change. Attachments were placed using a rectangular attachment template (Reliance Orthodontic Products, Itasca, IL, USA), Assure Plus (Reliance Orthodontic Products) and Transbond LR (3M Unitek, Monrovia, CA, USA). Study models were then randomly assigned to one of six groups:

- Group 1: No attachments placed
- Group 2: Rotation attachment placed on buccal surface mandibular right second premolar (rectangular vertical attachment, Reliance Orthodontic Products)
- Group 3: Rotation attachment placed on lingual surface of mandibular right second premolar (rectangular vertical attachment, Reliance Orthodontic Products)
- Group 4: Rotation attachments placed on buccal and lingual surfaces of mandibular right second premolar (rectangular vertical attachment, Reliance Orthodontic Products)
- Group 5: Rotation attachments placed on buccal surfaces of mandibular right first and second premolars and mandibular right first molar (rectangular vertical attachment, Reliance Orthodontic Products)
- Group 6: Rotation attachment placed on buccal and lingual surfaces of mandibular right first and second premolars and mandibular right first molar (rectangular vertical attachment, Reliance Orthodontic Products).

Scanning models using iTero Scanner

Initial models were scanned using the iTero Scanner (Align Technology, San Jose, CA), exported as STL files and imported into MotionView 3D software (Motion View, LLC, Hixson, South Africa). A treatment plan was prepared to correct rotation of the mandibular right second premolar by 3 degrees per aligner for a series of 10 aligners. No other tooth positions were altered. The 10-aligner treatment models for each group were exported in OBJ format for 3D printing.

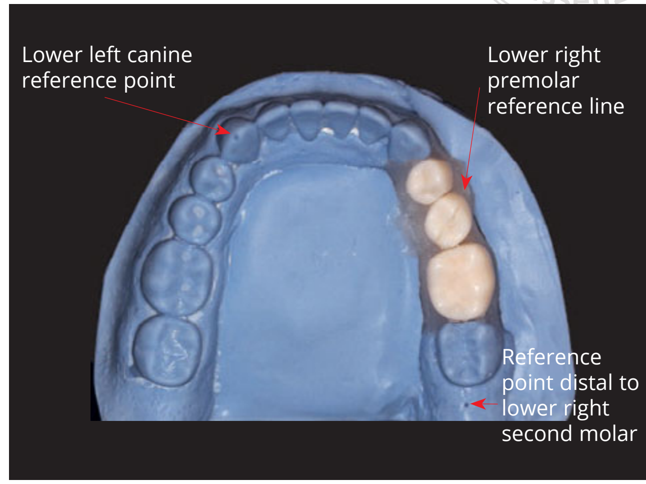

Fig 1 Final study model with lower right second premolar rotated.

Fabricating resin models using Juell 3D Flash OC

The Juell 3D OC printer (Park Dental Research, New York, NY, USA) was utilised in this study to fabricate the 60 total resin models used in this study at a resolution of 50 μ. The Juell 3D printer uses a stereolithography method of additive manufacturing with a digital light-processing projector (DLP) to cure each resin layer.

Fabricating aligners

Aligners were fabricated using 0.030-inch Zendura orthodontic clear aligner material (Bay Materials, Fremont, CA, USA) and a MiniStar S pressure-forming machine (Great Lakes Orthodontics, Tonawanda, NY, USA). Zendura sheets were heated for 40 s and immediately pressure formed over each resin model. Aligners were trimmed with a straight edge approximately 1 mm to 2 mm from the gingival margins (Cowley et al[15]).

Conducting trials

Each study model was placed in an ice water bath (5ºC) for 10 min initially to ensure that the aligner can be placed on the model without distorting the wax or initial tooth positions. While the model was in the ice bath, its corresponding

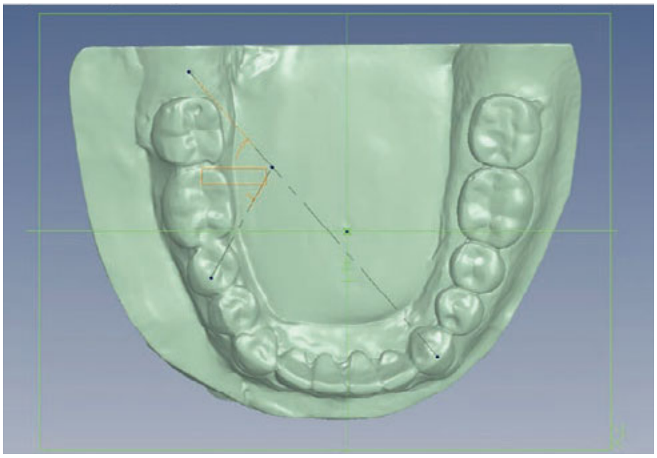

Fig 2 Example of angular measurement taken using Geomagic Design.

aligner was placed in a water bath set at 37ºC to simulate body temperature. Each aligner was then placed on its corresponding model and placed in a hot water bath (Model W20M, Sheldon Manufacturing, Cornelius, OR, USA) set at 50°C for 20 min. Since the aligner material is designed to be used in an intraoral environment, its properties cannot be guaranteed to be unaltered at high temperatures. For this reason, models were placed on stone platforms designed to elevate the model out of the hot water bath until the water level was just short of the apical margin of the aligner. This allowed for the wax to be heated by the hot water without immersing the aligner in the water. The ambient temperature at the surface of the water bath was measured at 38°C. Models were placed in the hot water for 5 min, then placed on a flat surface and occlusal pressure was applied to simulate occlusal forces and ensure seating of the aligners. The models were then replaced in the hot water bath for an additional 5 min for 10 min of total heating time. After heating, models were placed back in the ice water bath for 10 min prior to removing the aligner, and the model was taken to the OrthoInsight scanner for scanning.

Digital scans were taken initially and after each of 10 sequential aligners in order to assess both the total rotation as well as the rotation correction per aligner. Digital scans were taken using the Ortho Insight 3D laser desktop scanner (Motion View LLC) and scans were exported in OBJ format to be analysed using GeoMagic Design software (3D Systems, Rock Hill, SC, USA) to measure the degree of rotation correction after each aligner.

Measuring angles using Geomagic Design

Digital models were imported into the Geomagic Design software and oriented so that the occlusal surface was parallel to the X-Z axis. Once the correct orientation was achieved, lines were drawn according to the reference markers placed on the models. One line was drawn from the point distal to the mandibular right second molar to the cusp tip of the mandibular left canine. A second line was drawn through the occlusal reference line on the mandibular right second premolar. An angular measurement was then calculated at the inner angle of their point of intersection.

Statistical analysis

Statistical analysis of the data was performed using IBM SPSS (IBM, Armonk, NY, USA). Statistical tests run on the data included one way analysis of variance and used a significance level of $P < 0.05$. Calculations were also made for mean rotational change for each of the 10 aligners per group, mean rotational change per aligner per group overall, overall rotational change, and percentage of 30-degree intended rotational correction achieved.

Results

A one-way ANOVA was run to test the variance between the six groups with the significance level set at $P < 0.05$. The difference between all groups was statistically insignificant.

Discussion

Clear aligner therapy is a rapidly growing segment of the orthodontic market. According to the American Association of Orthodontists, the number of adults seeking orthodontic treatment grew by 58% from 1994 to 2010. In 2013, Align Technology[16] estimated that 31% of adult orthodontic cases were treated using the Invisalign system. In contrast to adolescents, adults typically have higher aesthetic demands, and although they may desire orthodontic treatment, they are more likely to reject treatment due to aesthetics. Due to the rising aesthetic demands of orthodontic patients, efforts have been made to provide aesthetic treatment solutions, including lingual braces, ceramic or plastic brackets, and clear plastic aligners.

Table 1 Mean rotational change per aligner

Group	Aligner 1	Aligner 2	Aligner 3	Aligner 4	Aligner 5	Aligner 6	Aligner 7	Aligner 8	Aligner 9	Aligner 10
1	1.6	1.64	2.09	1.64	1.65	1.7	1.88	1.84	2	1.92
2	1.92	1.97	1.99	2.46	2.67	2.23	2.51	2.23	2.2	2.08
3	2.15	1.37	0.87	1.68	2.49	2.09	2.66	2.37	2.58	2.61
4	1.9	1.58	1.58	1.16	1.75	2.29	2.34	2.4	2.2	2.83
5	0.94	1.31	0.47	0.95	2.42	2.2	2.08	2.22	1.66	2.11
6	1.03	0.75	0.89	1.01	0.8	0.57	0.73	0.6	1.03	0.94

Table 2 Mean rotational change per aligner for each group, mean total rotational change, and percentage of rotation corrected

Group	Mean Rotation Per Aligner	Mean Total Rotation	Percentage of 30° Rotation Corrected
1	1.81	17.96	59.87
2	2.21	22.25	74.17
3	2.13	20.87	69.57
4	2.08	20.03	66.77
5	1.68	16.37	54.57
6	0.85	8.34	27.8

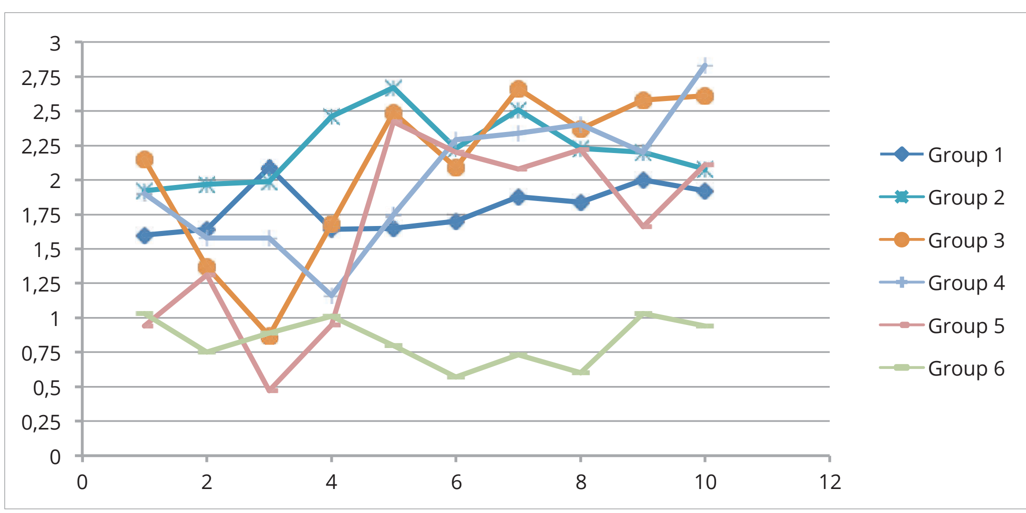

Fig 3 Mean rotation change for each aligner for each group.

Despite the rapid growth in demand for clear aligner therapy, very little is understood about its mechanism of action, indications and limitations. Few randomised clinical trials have been conducted, and much of the rationale for current treatment practices is based on anecdotal information, clinical opinion and case reports. The goal of this study was to develop an *in vitro* study model that could be applied to testing the efficacy of treatment using clear aligners. This study focused on controlling the rotation of round teeth, which has widely been reported as one of the most

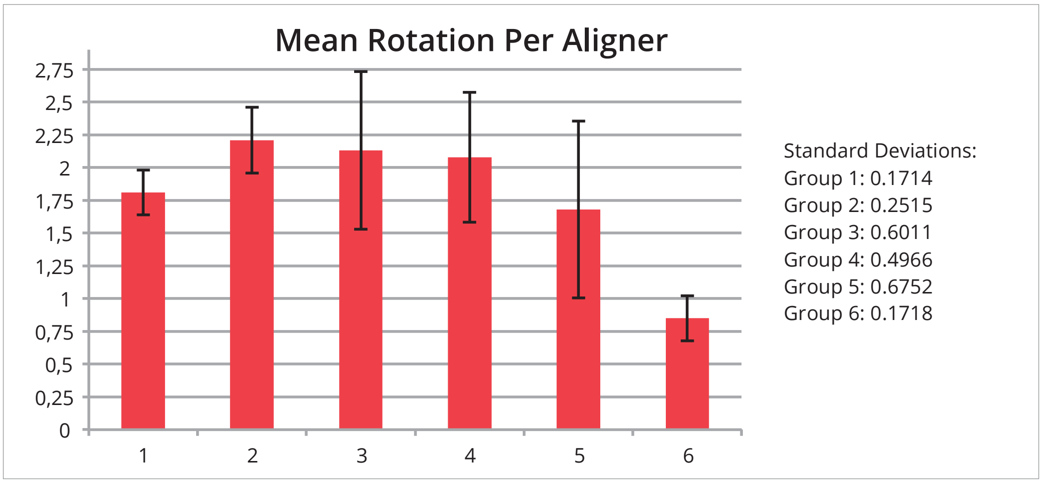

Fig 4 Mean rotation per aligner for all 10 aligners for each group.

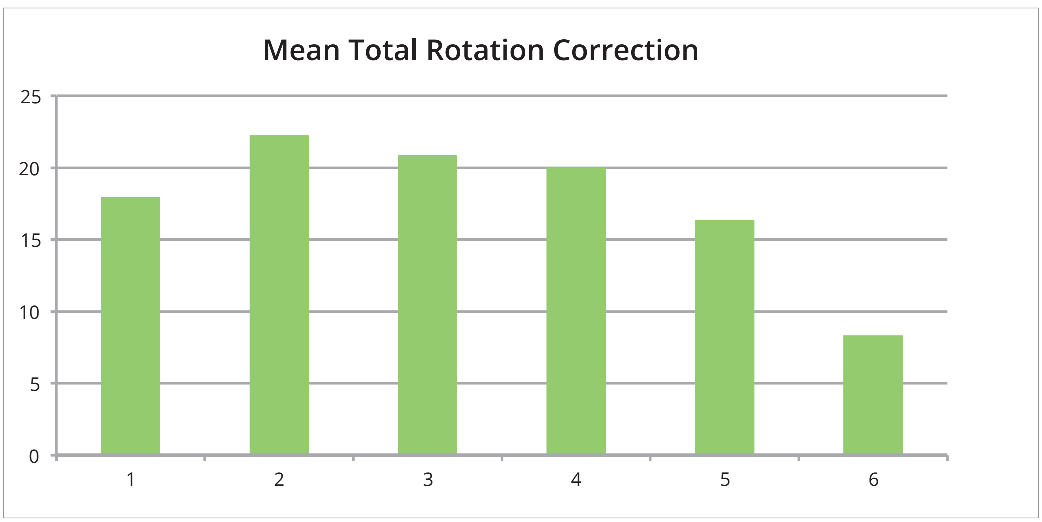

Fig 5 Mean total rotation correction for each group after a series of 10 aligners.

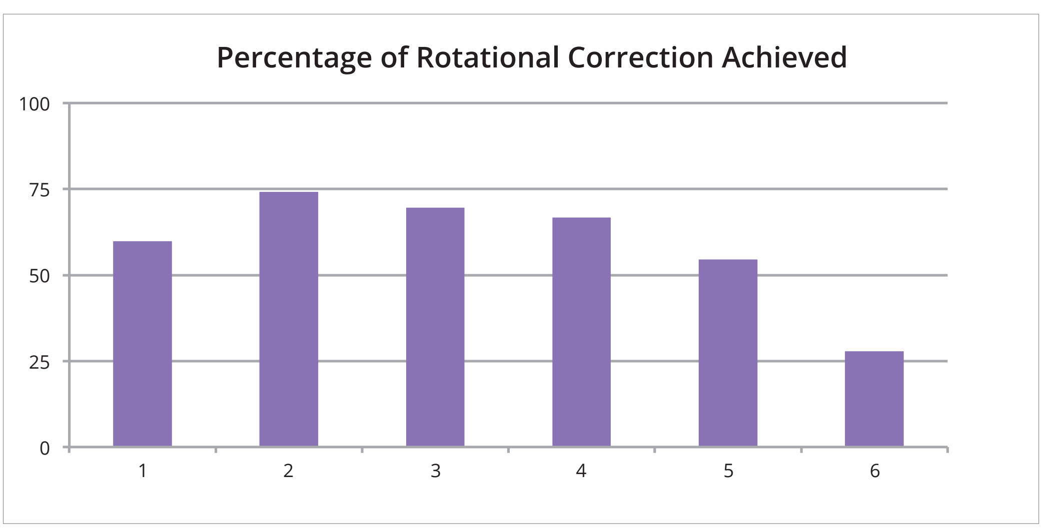

Fig 6 Percentage of initial 30-degree rotation corrected.

challenging movements to achieve with clear aligners, following extrusion[12,14,17]. Composite attachments, overcorrection, and adjusting aligners with thermoform adjusting pliers are three of the ways in which clinicians attempt to improve rotational control of round teeth[14]. This study assessed the differences between attachment location and number of attachments.

Although the results obtained were not statistically significant, observable differences were present among all groups. It must be noted that the use of two attachments, buccal and lingual to the mandibular right second premolar, did not provide greater rotational control, and therefore did not provide a force couple as theorised. The placement of a single buccal attachment provided the most rotational correction in this study. However, the group with no attachment had the smallest range of movement of the six groups, as shown in the standard deviation table in Figure 4. The small standard deviation suggests that the no attachment group provides more predictability of movement. The larger ranges observed in the other groups suggest that there may be clinical situations where attachments facilitate rotational correction and others where the attachment is of marginal or no improvement. From a clinical perspective, in the situation of rotational correction, one may strategise whether it would be advantageous to correct rotations with no attachments by planning for over-correction and revisions, as opposed to attempting to correct them with attachments and accepting that these movements may not be as predictable.

This is further illustrated in Figure 3, in which the no attachment group exhibits a linear pattern of rotational correction. This linear pattern supports the predictability of treating without attachments. Each consecutive aligner also appears to have a greater amount of rotation correction, suggesting that the subsequent aligner may be compensating for the shortcomings of the previous aligner. The flexibility of a plastic allows deformation and allows the aligner to "fit" the malocclusion in order to provide the necessary force to correct it. For this reason, each aligner was able to "fit" the rotated premolar, and despite the lag from the previous aligner, provide further correction. However, at some point, it would be expected that the aligners would no longer fit well, as the tooth continues to fail to fully track during treatment. This suggests it may be advantageous to account for lag or lack of correction when fabricating aligners from one stage to the next, rather than accounting for over-correction at the end of treatment, when it may be too late.

Clinical relevance and theoretical implications

One way to overcome challenges presented by clear aligner therapy is to use aligners as an adjunct to fixed appliances. The clinician can first place fixed appliances to align the teeth, and then take impressions after difficult movements are achieved to continue treatment with aligners. Alternatively, treatment can initiate with clear aligners, and transition to fixed appliances to achieve the movements that were not accomplished using clear aligners. However, for the segment of patients strongly opposed to fixed appliances, they may reject orthodontic treatment altogether, or the decision could be made to compromise treatment goals in order to limit movements to those which can be accomplished using clear aligners.

Many authors report that cases treated with clear aligners do not achieve pre-treatment goals with the first set of aligners and typically require further treatment[1,2,3]. When aligners fail to track as intended in the digital set-up, this is a source of frustration for patients and clinicians. If the decision is made for mid-course correction, new impressions will need to be taken, a new treatment simulation planned out, and new aligners made. If aligner fit is still acceptable, another option is to complete the current set of aligners and address the unsuccessful movements during refinement.

Limitations and suggestions for future research

Clear aligner research has numerous variables and limitations. For this study, the greatest limitation is that it is an *in vitro* model. The model utilised Typodont teeth embedded in wax, which would lead to results different than that expected *in vivo*, where biological factors such as the presence of the periodontal ligament would be a factor. Additionally, a wax model is unable to take into account the effects of saliva, occlusal forces, and intraoral wear on the aligner.

The primary goal of this study was to evaluate the efficacy of attachments to correct rotation of a mandibular premolar, one of the most difficult movements to achieve using clear aligners. Increasing treatment efficiency would benefit clinicians, patients, and the clear aligner industry by reducing tooth lag, reducing the need for mid-course correction, and decreasing the time and number of aligners needed for the refinement phase. Further research is necessary to evaluate different attachment shapes and designs and whether they can improve efficacy of tooth movement. Further research is also necessary to evaluate and compare different materials and different thermoforming techniques and their effects on the force delivery properties of aligners.

Conclusion

Analysis of the results of this study yields the conclusion that presence and number of attachments is not significantly more effective than having no attachments. This is in agreement with conclusions by Kravitz et al in 2008[14], and again with Simon et al[12] in 2014. Attachments are commonly thought to be analogous to traditional brackets, however clear aligner treatment has a force delivery and tooth movement mechanism that although not fully understood, is uniquely different from traditional fixed appliance treatment. It appears from this study that increasing the number of attachments would impede rotational correction, and the two groups (5 and 6) with the most attachments had the smallest degree of rotational correction of the five attachment groups. One possible explanation is that this finding could be attributed to the thermoforming process. Thermoforming with multiple attachments will lead to more thinning of the plastic and loss of adaptation, resulting in less efficient force delivery. In addition, in this study it appeared that the preciseness of fit of the aligner was reduced when multiple attachments were present. This is thought to happen because the plastic aligner is meant to flex and conform to a malocclusion, and bring teeth into alignment by resisting deformation and returning to its original shape. The presence of multiple attachments in the same quadrant could make it more difficult for the aligner to stretch and conform to the teeth in that quadrant. It would follow that inadequacies in aligner seating and engagement of attachments would lead to inefficiencies in tooth movement. One study reported similar findings, theorising that with an aligner that does not fit ideally, attachments could not only decrease force delivery, but in some instances can cause counter-moments and produce movements in the direction opposite to that intended[12]. This study shows that use of attachments with thermoformed orthodontic appliances is relatively complex and clinicians should consider the variables involved to use them judiciously, taking each patient's unique conditions and circumstances into careful consideration.

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