Original Article

Effects of variable attachment shapes and aligner material on aligner retention

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ABSTRACT

Objective: To evaluate the retention of four types of aligners on a dental arch with various attachments.

Materials and Methods: For this study, three casts were manufactured, two of which contained attachments (ellipsoid and beveled), and one without any attachments to serve as a control. Four types of aligners were thermoformed: Clear-Aligner (CA)-soft, CA-medium, and CA-hard, with various thicknesses, and Essix ACE. Measurements of vertical displacement force during aligner removal were performed with the Gabo Qualimeter Eplexor. Means and standard deviations were next compared between different aligner thicknesses and attachment shapes.

Results: CA-soft, CA-medium, and CA-hard did not present a significant increase in retention, except when used in the presence of attachments. Additionally, CA-medium and CA-hard required significantly more force for removal. Essix ACE demonstrated a significant decrease in retention when used with ellipsoid attachments. The force value for Essix ACE removal from the cast with beveled attachments was comparable to that of CA-medium. Forces for aligner removal from the model without attachments showed a linear trend. Essix ACE did not show a continuous increase in retention for each model. Overall, ellipsoid attachments did not present a significant change in retention. In contrast, beveled attachments improved retention.

Conclusions: Ellipsoid attachments had no significant influence on the force required for aligner removal and hence on aligner retention. Essix ACE showed significantly less retention than CA-hard on the models with attachments. Furthermore, beveled attachments were observed to increase retention significantly, compared with ellipsoid attachments and when using no attachments. (*Angle Orthod.* 2015;85:934–940.)

KEY WORDS: Aligner therapy; Retention; Attachment shapes; Thermoplastic appliances

INTRODUCTION

Thermoplastic appliances have an extensive history in orthodontics. As a result of new technology and materials, thermoplastic appliances have evolved over the past 10 years and can now be used for full orthodontic treatment.[1]

Numerous companies have developed aligners with various features. For example, Invisalign (Align Technology, San Jose, Calif) uses identical aligner material throughout treatment and a scalloped margin design. Clear-Aligner (Scheu Dental, Iserlohn, Germany) offers aligners in three different thicknesses (0.5 mm, 0.625 mm, and 0.75 mm) for each stage in treatment.[2]

Furthermore, different attachment shapes have been designed (CA Power Grip,[2] Invisalign attachments[3]) to enhance retention and facilitate complex movements such as rotation.[4] The variations between different aligners (such as lab fabrication vs online order of aligners, or digital versus manual setups) enable providers to select their preferred techniques. In order to make an informed decision, the orthodontist requires awareness about aligner properties. However, research on aligners is limited and additional

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Figure 1. Stone model with ellipsoid attachments, which were added to both premolars. Attachment shapes inspired by Invisalign attachments.

assessment of scientific features is not well investigated.

Retention remains an unquantified variable in aligner use. Aligners require flexibility for insertion and removal, but need rigidity to exert the force necessary for orthodontic tooth movement. Clinicians and aligner companies attempt to increase an aligner's retention by using thicker material and retention attachments, and extending the margin of the aligner over the gingiva. To date, there is no evidence as to which aligner design and material provides optimal retention when combined with different attachment shapes.[5–7]

This study analyzes how aligner materials from various companies influence retention in combination with two different attachment shapes. It is commonly said that softer material and rounder attachments provide less retention than more rigid material and edgy attachments, but no data have yet been published to prove this. The numerical results from this study can be used to create guidelines for optimized future aligner therapy. Thus, orthodontists using aligner therapy will have a broader understanding of the numerous aligner materials and attachments being offered by so many different companies. This will give them the chance to use materials and attachments wisely according to the needs of each case. In this study, two of the major aligner companies were compared. Scheu Dental is a German family-owned company with expertise in thermoforming machines and aligner materials that has been producing lab products for aligner fabrication for three generations. The Biostar thermoforming machine by Scheu Dental was used in this study. The company's own system for aligner therapy is called Clear-Aligner and consists of three aligners for each setup. Each aligner is made of the same material but varies in thickness (CA-soft, -medium, -hard). These three CA aligners were examined in the present experiment. For comparison with a different material type, Essix ACE, aligners were also included in the study. Dentsply Raintree Essix is an American company with decades of experience in

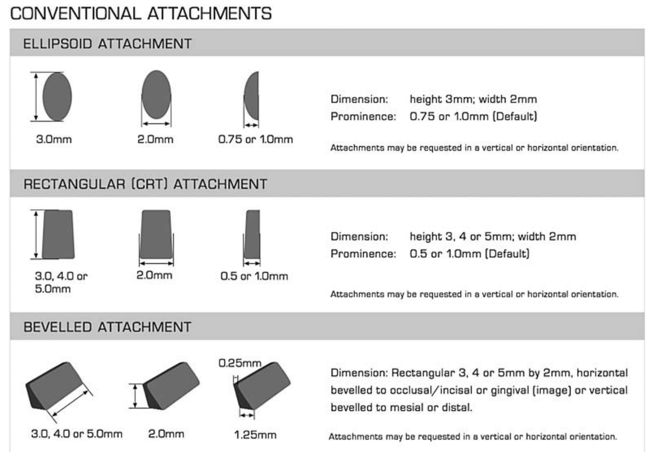

Figure 2. Attachment dimensions. Ellipsoid attachments were oriented vertically and measured 3 mm in height, 2 mm in width, and 1mm in depth. Rectangular beveled attachments were oriented horizontally, and were 2 mm high, 3 mm wide, and 0.25 mm deep toward the incisal edge and 1.25 mm deep toward the gingival margin.

orthodontic plastic fabrication. Essix ACE is one of the thermoforming plastics from this company used for orthodontic aligners. Testing up-to-date plastic materials aims at being a clinically relevant study providing information for orthodontists currently using—or considering—aligner therapy.

MATERIALS AND METHODS

Three precision polyvinyl siloxane impressions (Bisico, Bielefelder Dentalsilicone GmbH & Co KG, Bielefeld, Germany) of a human upper jaw with mild misalignment and missing third molars were taken and poured in die stone. Two casts were modified by the addition of plastic attachments on all premolars (Figure 1). In this study we used attachments closely related to the attachments termed "conventional attachments" by Invisalign.[8] Two types of conventional attachments with the following dimensions were applied (Figure 2):

1. ellipsoid attachments (height: 3 mm, width: 2 mm, depth: 1 mm)
2. rectangular attachments, which were beveled toward the incisal edge (height: 2 mm, width: 3 mm, depth: 0.25 mm incisally and 1.25 mm gingivally).

The third cast contained no attachments and served as a control. The models were then duplicated and recreated using a nonabrasive, hard plastic material (Figure 3). Premolars containing attachments were substituted with their metal equivalents. Four different types of aligners were thermoformed over each of the three models using a Biostar vacuum thermoforming machine (Scheu Dental): Clear-Aligner (CA)-soft

Figure 3. Duplicated model of cold-curing dental resin (Palapress-vario, Heraeus Kulzer, Hanau, Germany) in a Biostar Thermoforming Machine (Scheu Dental).

(0.5 mm), CA-medium (0.625 mm), CA-hard (0.75 mm), and Essix ACE (0.76 mm).

Three types of CA foils were selected to test different thicknesses of the same material type. Essix ACE is similar in thickness to CA-hard, but has a different material composition. CA is made of glycol-modified polyethylene terephthalate designed by Scheu Dental. Alternatively, Essix ACE is a copolymer of polyethylene terephthalate from Dentsply Raintree Essix, York, Pennsylvania.

To avoid deviations, special emphasis was put on accurate aligner and model fabrication. Aligners were thermoformed as per manufacturing code to avoid overheating and inconsistency during each process. All listed material thicknesses refer to the thickness prior to thermoforming. After thermoforming, all aligner thicknesses were remeasured to ensure homogeneity. Aligner thickness was decreased after thermoforming (0.017 mm–0.022 mm); however, this change was consistent and universally observed, thus suggesting minimal fabrication error. All aligners were trimmed along the border of the model base to create an unvarying reference.

Casts were modified by drilling holes into a reproducible location of the cast. One 6-mm diameter hole was made through the center of the cast base for fixation of the cast inside the measuring device and secured by a tight screw. The placement was determined by the intersection of a line along the palatal suture and one leading through the occlusal holes using a laser level (Figure 4). Two additional holes (3 mm in diameter, 5 mm in depth) were also drilled into the occlusal surfaces of the first molars at the edge of the mesiolingual cusp and the central fissure. These depressions allowed for the placement of a metallic stop attached to a steel rope. Both of the ropes lead from inside the molar, through the thermoformed aligner, and into the measuring machine, which delivered a vertical pulling force on the rope. The stop on the end of the rope did not interfere with the hole perimeters, avoiding friction which could affect the trials. Nor did it interfere with the anatomy of the tooth, which allowed the aligner to cover the teeth in its original, thermoformed shape.

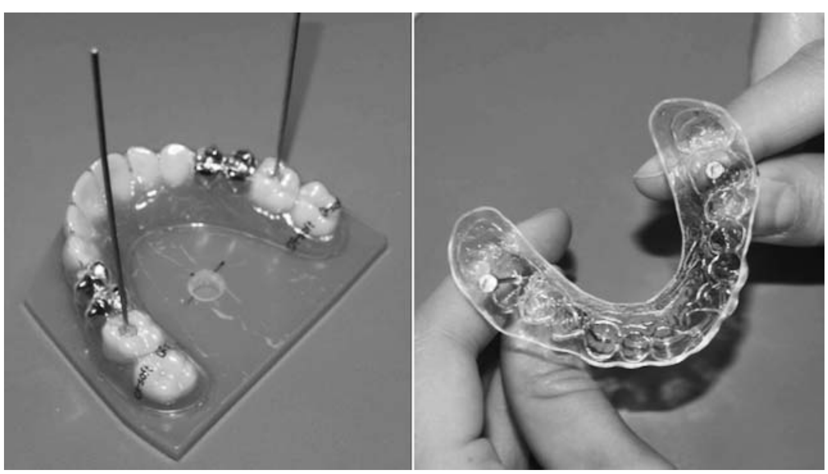

Figure 4. Reproducible locations of holes on the model base (6 mm in diameter) and the occlusal surfaces (3 mm in diameter and 5 mm in depth) of the first molars. The central mounting hole was used for fixation of the model in the Gabo Qualimeter Eplexor (GQE). The location was determined with one median line through the location of the palatal raphe intersecting with a line through the mesiolingual cusps of the first molars. The molar holes provided room for the stops of two steel ropes that passed through the aligner into the bolting apparatus on the GQE.

Figure 5. Model inside the GABO Qualimeter Eplexor (GQE). Aligner attached via steel ropes running straight from the first molars through the aligner to the bolting apparatus. The upward displacement force was measured in 10-second intervals until the aligner was removed from the model.

Measurements were made while removing the aligner from the dental arch using a Gabo Qualimeter Explexor (GQE; Testanlagen GmbH, Ahlden, Germany). To avoid shearing forces during aligner removal, a bolting apparatus was manufactured to allow the steel ropes to connect perpendicularly from the teeth to the apparatus.

The minimum force needed to remove aligners from the cast was measured using the same cast with a new aligner for each of the four test runs. Vertical displacement force was applied perpendicularly on the steel rope, leaving the cast in an unchanged position (Figure 5). The force applied during aligner removal was registered, while the machine continued to move upward in steps of approximately 10 seconds. The highest force that dislodged the aligner from the dental arch was used to calculate an average force for each of the four aligners.

Three key aspects influencing aligner retention were measured in this study: (1) whether ellipsoid or beveled attachments improve retention; (2) whether increased material thickness or different material composition increases retention; and (3) a cross comparison between different aligners (CA-soft, CA-medium, CA-hard, ACE) and attachments (none, ellipsoid, beveled).

RESULTS

Effect of Attachment on Aligner Retention

First, the effectiveness of ellipsoid versus beveled attachments on aligner retention was compared with control having no attachment (Figure 6A–C). Vertical displacement force was measured in Newtons for each aligner material. The first group of four columns shows vertical displacement forces for CA-soft, -medium, and -hard and Essix ACE from the model, which contained no attachments (Figure 6A). The second group illustrates the vertical displacement force of each aligner while being removed from the model with ellipsoid attachments on all premolars (Figure 6B). The third group demonstrates removal from the cast containing beveled attachments (Figure 6C). When no attachment was used, a significant and linear trend was observed. The first four columns in the illustrated chart increased from CA-soft toward Essix ACE continuously. This linear pattern reappears for all CA aligner materials in the second and third group of columns. However, a distinct drop in aligner retention was registered with Essix ACE when either ellipsoid or beveled attachments were implemented (second and third group of columns).

When comparing overall retention of each material on the cast containing ellipsoid attachments with the control group, no significant increase was seen (Figure 6A,B). The expected increase compared with

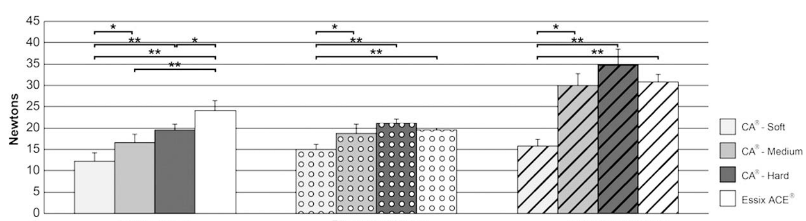

Figure 6. Quantification of variable aligner material on retention. **(A)** Vertical displacement forces (Newtons) of each aligner material during removal from the control cast containing no attachments. (**B)** Vertical displacement forces of each aligner material during removal from the cast containing ellipsoid attachments. (**C)** Vertical displacement forces of each aligner material during removal from the cast containing beveled attachments. Each column represents one of the tested aligner materials (CA soft, medium, hard; Essix ACE).

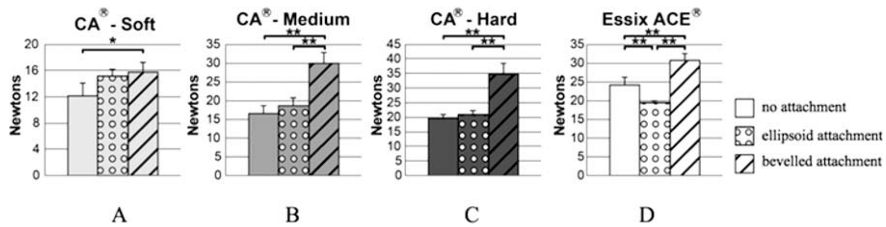

Figure 7. Quantification of variable attachments on retention. **(A)** CA soft aligner removal from three different casts containing either no attachments, ellipsoid, or beveled attachments. (**B)** CA medium aligner removal from three different casts containing either no attachments, ellipsoid, or beveled attachments **(C)** CA hard aligner removal from three different casts containing either no attachments, ellipsoid, or beveled attachments **(D)** Essix ACE aligner removal from three different casts containing either no attachments, ellipsoid, or beveled attachments.

control in retention was observed only for the cast containing beveled attachments (Figure 6A–C).

In summary, the casts containing ellipsoid attachments did not significantly increase retention. Additionally, Essix ACE aligners did not demonstrate a linear behavior similar to that of CA aligners.

Effect of Aligner Material on Retention

1. material thickness
2. material composition

As a second part of our study, we compared each aligner's retention during removal from the casts. Two components were analyzed. First, material thickness was compared using CA-soft, CA-medium, and CA-hard. Second, Essix ACE and CA-hard were compared for material composition analysis.

When CA-soft was removed from each cast, a gradual increase in retention was observed; however, this was not statistically significant (Figure 7A). A statistically significant increase of 60.12% was observed when the CA-medium aligner was removed from the cast with beveled attachments (Figure 7B).

CA-hard also demonstrated a significant increase in retention (65.28%) during removal from the cast with beveled attachments (Figure 7C).

In our material composition analysis, CA-hard and Essix ACE showed contrasting results. Essix ACE demonstrated an 80.63% decrease in retention between the cast with no attachments and the cast with ellipsoid attachments. This was not observed during any other material testing of this study (Figure 7D). Additionally, there was a significant increase in retention between the cast containing ellipsoid attachments and the cast with beveled attachments (57.90%).

Further Observations and Trends

A significant increase in retention was observed for CA-medium compared with CA-soft throughout all groups (Figure 7A–C). CA-medium demonstrated a 36% increase in retention without any attachments. Using beveled attachments, CA-medium showed a 90% increase in retention. Finally, with ellipsoid attachments, CA-medium had a 23% increase in retention. CA-medium did not differ significantly from CA-hard in any of the groups.

When comparing CA-hard and Essix ACE, Essix ACE demonstrated increases in retention without attachments. There were no significant differences in retention when comparing each of these two materials' retention on the casts with ellipsoid attachments (Figure 7C,D).

An unexpected, yet interesting finding from a cross comparison was the force required for Essix Ace aligner removal from a cast with ellipsoid attachments (Figure 7D, center column). It required less force than the amount needed to remove the CA-hard aligner from a cast without any attachments (Figure 7C, first column).

DISCUSSION

Our investigation provided evidence that disproves the dogma that attachments enhance aligner retention under any circumstance. Our findings suggest that only certain attachments increase retention when used with increased aligner thickness or a certain material. The following will elaborate on each of the investigated categories.

Effect of Attachment on Aligner Retention

We observed that attachment shapes affect retention, especially in combination with harder material.

CA-medium and CA-hard show that a greater amount of force was required to remove an aligner from a cast containing beveled attachments, compared with a model having either ellipsoid attachments or no attachments (Figure 6). The results obtained from comparing retention on the cast with no attachments to the cast with ellipsoid attachments show no significant difference between CA-soft, CA-medium, or CA-hard (Figure 6A,B). Essix ACE demonstrated a significant decrease in retention here. This suggests that ellipsoid attachments do not increase aligner retention significantly under all circumstances.

Effect of Aligner Material on Retention

The linear increase in retention, when comparing CA-soft, CA-medium, and CA-hard, suggests that retention varies based on material thickness (Figure 6A–C). In contrast, Essix ACE demonstrated decreased retention compared with CA-hard when removed from the cast with ellipsoid attachments, as well as the cast with beveled attachments (Figure 6B,C). Since CA-hard and Essix ACE have approximately the same thickness but different compositions, this suggests that retention depends on material composition and does not necessarily correlate with material thickness. This is in line with the Hahn et al. findings.[9]

Also, when analyzing the results of Essix ACE, we found that a significant decrease in force during aligner removal from the cast with ellipsoid attachments suggests that attachment types have different effects on different materials. Therefore, the effect of attachments correlates with the material of each individual aligner.

Further Observations and Trends

The similar values in retention between CA-medium without attachments and CA-soft with beveled attachments suggest that the use of CA-soft with beveled attachments can be replaced with CA-medium with no attachments in order to create the same amount of retention.

Numerous investigators have reported additional factors that can influence aligner retention, including attachment placement, marginal design of aligners, and clinical crown size.[5–7] The evidence and the results from this study provide guidance for selecting an aligner from a wide selection of brands and materials. When using an aligner system that provides in-office fabrication, one must take into consideration that attachments do not necessarily provide adequate anchorage on the teeth in every case. It is crucial for successful treatment to know the material type and thickness before combining it with various attachments.

Limitations and Future Studies

As our study analyzed two factors contributing to retention, future studies should investigate additional factors that could influence aligner retention. Considering other investigations in this field,[5–7,9] one persistent experimental setting would make previous findings and our measurements more comparable, since differences in the bolting apparatus, model design, and measuring device impede drawing one conclusion for aligner retention from the listed findings.

The small sample size in this study inherited a limited perspective that needs to be widened in future studies. Since our study revealed the significance of material composition on aligner retention, additional trials should be conducted to compare different material types of the same thickness to determine which material component contributes to increased retention. Future clinical studies should include the effect of body temperature, saliva, and patient comfort on aligner retention.

Aligner friction is also influenced by the thermoforming process, according to Hahn et al.[9] This can be avoided in the future by using modern three-dimensional printing technology, which enables various thicknesses to exist within one aligner: a thicker portion for teeth that do not require movement and a thinner, more flexible portion for misaligned or crowded teeth that do.

CONCLUSIONS

- Ellipsoid attachments showed no significant effect on retention in the aligner used in this study.
- Essix ACE showed statistically significant less retention on models with attachments compared with CA-hard having similar thickness.
- The use of beveled attachments increased retention significantly.

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