The Change of Clear Aligner Retention after Removal and Insertion of the Aligner
การเปลี่ยนแปลงแรงยึดของเครื่องมือจัดฟันถอดได้แบบพลาสติกใสหลังจากการถอดและใส่เครื่องมือ

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ABSTRACT

This study aimed to evaluate the effect of the number of insertion and removal of an aligner on the aligner retention. Retentive forces of an aligner during aligner removal were evaluated and compared for 14 consecutive days by a universal testing machine (N=3). The mean retentive force of aligner removal on the 1st day was 63.711 ± 6.714 N and that on the 2nd day sharply decreased to 41.667 ± 6.816 N. Those on the 3rd to 14th day were not significantly different. After 14 days of insertion and removal for a total of 42 cycles, the aligner area gingival to the attachments was noticeably stretched, which might be the reason for retentive force reduction of aligner, while the attachments were not visibly worn away.

บทคัดย่อ

งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาผลของจำนวนครั้งในการถอดใส่เครื่องมือจัดฟันถอดได้แบบพลาสติกใสต่อแรงยึดของเครื่องมือจัดฟัน แรงยึดของเครื่องมือจัดฟันในขณะถอดเครื่องมือจัดฟันถูกวัดและเปรียบเทียบเป็นเวลา 14 วันติดต่อกัน โดยใช้เครื่องทดสอบอเนกประสงค์ (จำนวนตัวอย่าง=3) แรงยึดเฉลี่ยของการถอดเครื่องมือจัดฟันในวันที่ 1 มีค่า 63.711 ± 6.714 นิวตัน ในวันที่ 2 ลดลงอย่างชัดเจนเหลือ 41.667 ± 6.816 นิวตัน ส่วนแรงยึดเฉลี่ยของการถอดเครื่องมือจัดฟันในวันที่ 3 ถึง 14 นั้นไม่แตกต่างกันอย่างมีนัยสำคัญ หลังจากการถอดและใส่เครื่องมือจัดฟันเป็นเวลา 14 วัน รวมทั้งหมด 42 ครั้ง พบว่าเครื่องมือจัดฟันบริเวณที่อยู่ด้านเหงือกต่อหลักยึดถูกยืดออกอย่างชัดเจน ซึ่งอาจเป็นสาเหตุของการลดลงของแรงยึดของเครื่องมือจัดฟัน ในขณะที่หลักยึดไม่ได้มีการสึกที่มองเห็นด้วยตาเปล่า

Keywords: Clear Aligners, Retention
คำสำคัญ: เครื่องมือจัดฟันถอดได้แบบพลาสติกใส แรงยึด

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Introduction

Clear aligners have long been introduced to orthodontic treatment. They are made from a clear thermoformed plastic sheet vacuum over a set-up model and initially usually is used for minor tooth movement (Nahoum, 1964). The number of adults seeking orthodontic treatment has increased recently. Most of them preferred clear aligners because they were deemed more attractive (Rosvall et al., 2009). Currently, a sequence of clear aligners can be used to treat complex malocclusion because of technological advancements in aligner materials, design and manufacture together with uses of auxiliaries, miniscrew anchorages, and attachments (Bouchez, 2019).

Attachments are small tooth-colored bumps made of resin composite bonded to the tooth surface to enhance aligner retention and facilitate specific tooth movements (Bouchez, 2019). Attachments are various in shapes and sizes, for example, horizontal rectangular attachments. They can improve tooth intrusion, extrusion, and aligner retention (Bouchez, 2019). Previous studies showed that shape and position of attachment, aligner material and thickness, and aligner margin design affected aligner retention (Jones et al., 2009; Dasy et al., 2015; Cowley et al., 2012).

For engineering purposes, wear is progressive damage to a surface caused by relative motion with another substance as well as changes in dimension or geometry of a part due to plastic deformation. Development of a network of cracks in the surface are included in the definition of wear (Bayer, 2004). Cycles of stressing and unstressing of the materials can develop cracks and lead to a loss of material from the surface (Bayer, 2004). Clinical wear of attachment and aligner is a complex phenomenon that depends on many variables. Insertion and removal of aligner may wear the attachment, and/or deform the aligner which leads to the reduction of aligner adaptation, improper active surface to create a desirable force system, and less retention. Therefore, an understanding of material properties and other factors affecting retentive force change could be helpful to attain and control retentive force during aligner removal.

Objectives of the study

This study aimed to compare a mean retentive force from aligner removal in each day, for 14 days, consecutively.

Methodology

Study Sample

The study sample was three identical sets of a clear aligner and a maxillary resin model with an occlusally beveled horizontal rectangular attachment (height: 2 mm, width: 3 mm, depth: 0.25 mm occlusally, and 1.25 mm gingivally) on the mid-buccal surface of all maxillary premolars (N=3).

Sample fabrication

A stone model of a patient's well-aligned maxillary dentition was scanned with Ceramill® Map 400 and Ceramill® Mind (Amann Girrbach GmbH, Austria). The 3D scanned image was edited in Autodesk Meshmixer 3.5 (Autodesk Inc., U.S.).

The scanned image was firstly edited (Fig. 1A and 1B) and three models were printed with photopolymer grey resin (Formlabs, U.S.) at a resolution of 50 µm. Each model was used with a vacuum thermoforming machine (Biostar®, Scheu Dental Technology, Germany) and thermoformed plastic sheets (Essix ACE® 125mm circle .035", Dentsply Sirona Orthodontics, U.S.) for making an attachment template and a clear aligner. The sheets were vacuumed over the model as per manufacturing code of 123. The templates and aligners were trimmed as a straight-line margin from the gingival zenith of the central incisors to the gingival zenith of the second molars (Fig. 1E).

The scanned image was secondly edited (Fig. 1C and 1D) and three models were printed with photopolymer grey resin (Formlabs, U.S.) at a resolution of 50 µm. Flowable resin composite (Tetric N-Flow: incisal shade, Ivoclar Vivadent AG, Liechtenstein) was injected into attachment windows of the template. The template was completely seated over the model, and the attachments were light-cured for 20 seconds (1200 mW/cm^2, Mini LED SuperCharged, Acteon, UK). The attachment surfaces were not polished after template removal (Fig. 1F).

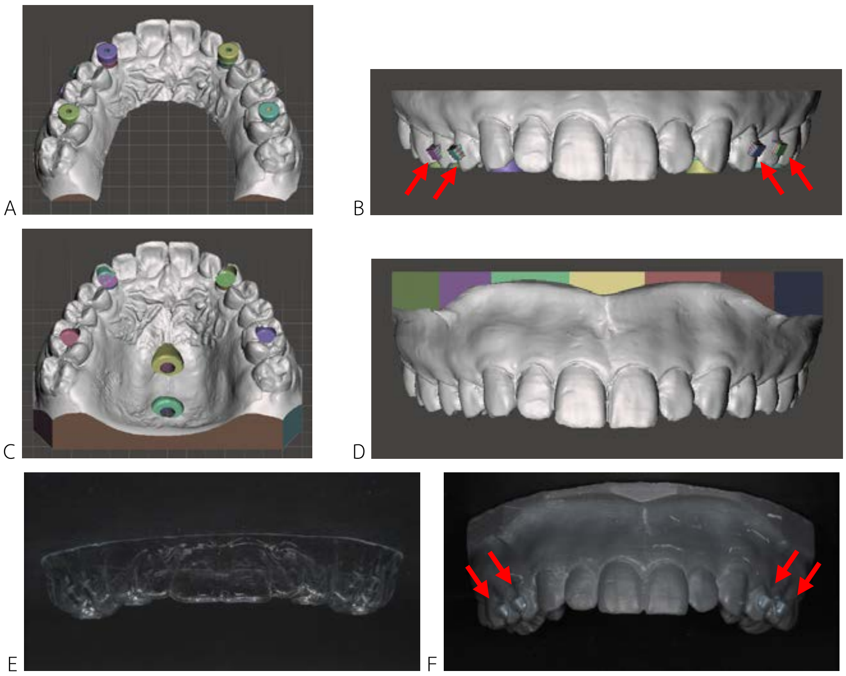

Figure 1 Top back view (A) and front view (B) of the model which was used for making the attachment templates and the aligners, red arrows point at attachments. Top back view (C) and front view (D) of the model on which resin composite attachments were to be placed. Vacuum-formed attachment template/clear aligner (E). Resin model (F), red arrows pointed at attachments.

Experiment and measurement

The aligner was initially completely seated on the model (Fig. 2). The insertion and removal of the aligner were conducted by a universal testing machine (Shimadzu EZ test, Japan). The directions of the insertion and removal were perpendicular to the occlusal plane. The aligner was pulled at a rate of 6.35 mm/min (Cowley et al., 2012) with a 500 N load cell until visibly completely removed and was pushed back into the initial position. The aligner was removed and reinserted for 42 cycles, simulating the removal and insertion 3 times/day. A minimum force needed to remove the aligner from the resin model which represented a retentive force was evaluated by the universal testing machine. Three consecutive retentive forces were calculated as a mean retentive force of each consecutive day.

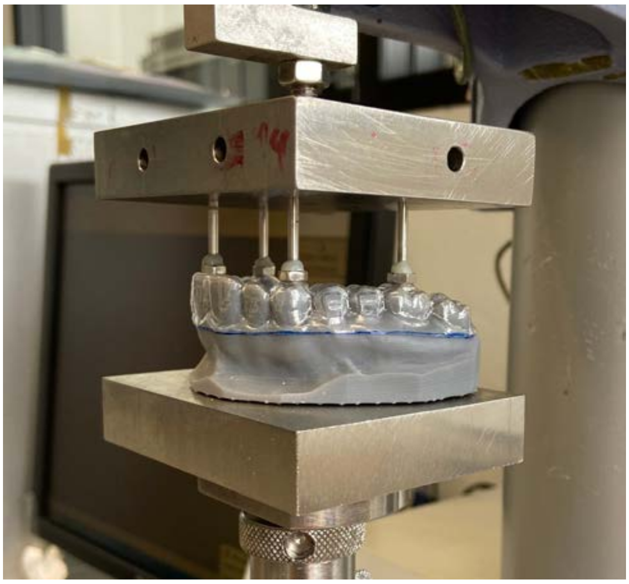

Figure 2 Installation of the sample to the universal testing machine.

Statistical Analyses

SPSS statistics version 22.0 software (IBM, U.S.) was used for descriptive and inferential statistical analyses. The normality of the data was verified by Shapiro-Wilk test. The mean retentive forces were analyzed by one-way repeated measure ANOVA test followed by post-hoc analysis. A statistically significant difference was considered to present at $P < 0.05$.

Result

Aligner area gingival to the attachments was markedly stretched (Fig. 3) while the attachments were not visibly worn away after 14 days of insertion and removal for a total of 42 cycles. The mean retentive forces of aligner removal were normally distributed. That of the first day was 63.711 ± 6.714 N and that of the second day sharply dropped to 41.667 ± 6.816 N (Fig. 4). Pairwise comparison showed that aligner removal of the first day had significantly higher mean retentive force than those of the others; that of the second day had significantly higher mean retentive force than those of the eleventh to the fourteenth day (Fig. 5), and those of the third to the fourteenth day had no significantly different mean retentive force.

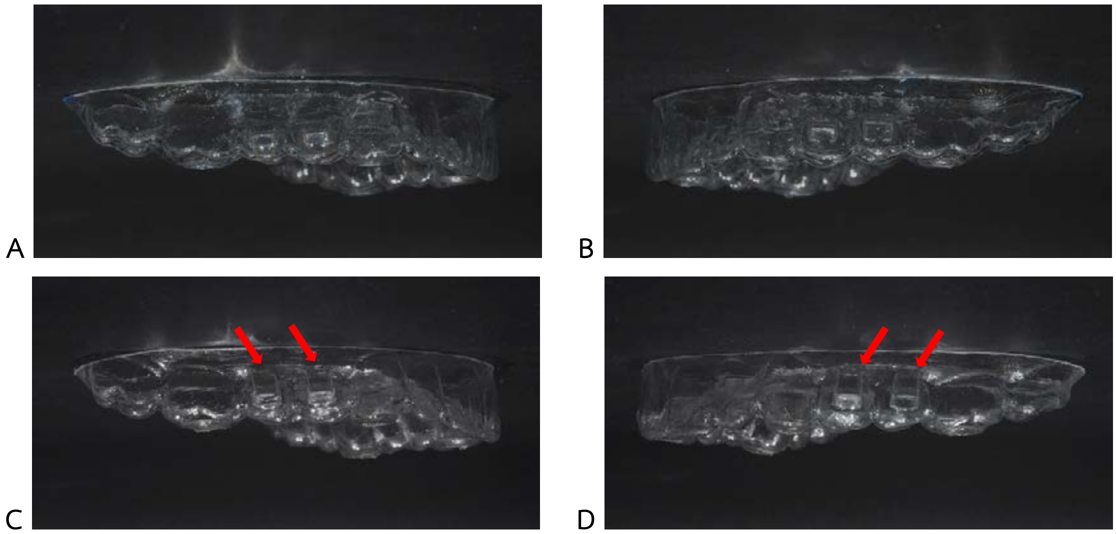

Figure 3 Before (A and B) and after (C and D) insertion and removal of clear aligner for 42 cycles. Red arrows point at deformed areas of the aligner.

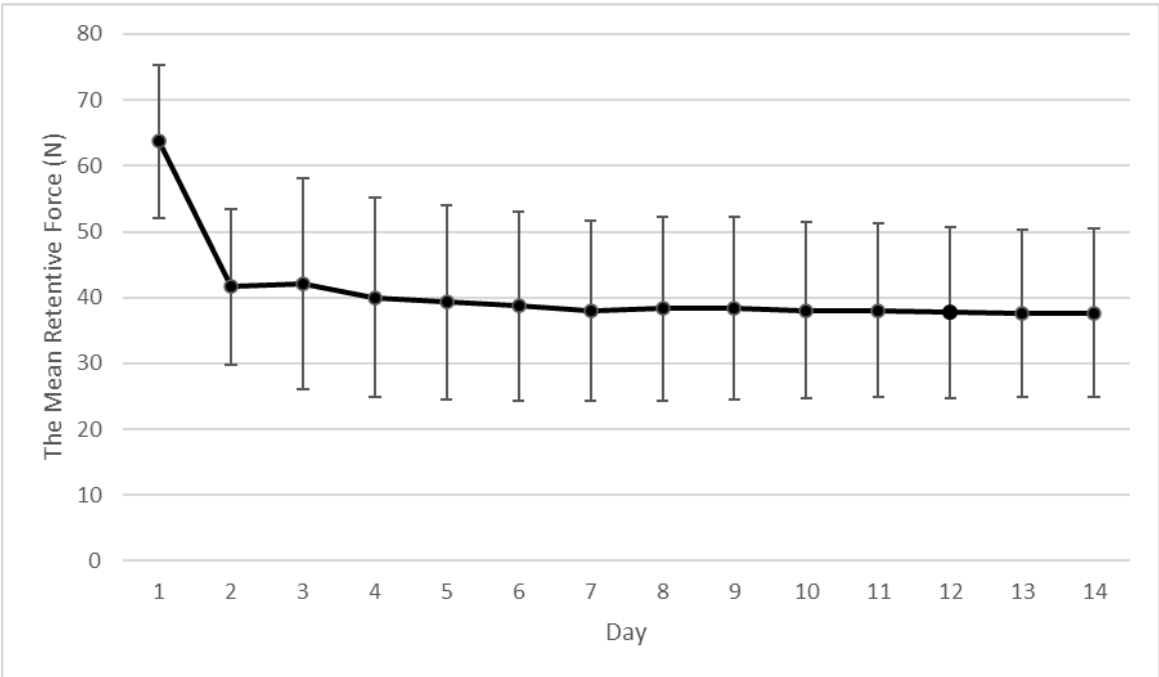

Figure 4 The mean retentive force of aligner removal of each day.

Table 1 Pairwise comparison of the mean retention of aligner removal of the first (left table) and second (right table) days to those of the others.

Day (I)	Day (J)	Mean Difference (I-J)	Std. Error	Sig.[b]
1	2	22.045*	1.535	.005
	3	21.621*	3.719	.028
	4	23.704*	3.067	.016
	5	24.435*	2.803	.013
	6	25.004*	2.579	.010
	7	25.680*	2.108	.007
	8	25.420*	2.209	.007
	9	25.357*	2.157	.007
	10	25.694*	1.938	.006
	11	25.715*	1.868	.005
	12	25.979*	1.720	.004
	13	26.078*	1.534	.003
	14	26.017*	1.793	.005

Day (I)	Day (J)	Mean Difference (I-J)	Std. Error	Sig.[b]
2	1	-22.045*	1.535	.005
	3	-.424	2.607	.886
	4	1.659	1.991	.492
	5	2.390	1.770	.309
	6	2.960	1.538	.194
	7	3.635	1.069	.077
	8	3.375	1.229	.111
	9	3.312	1.232	.115
	10	3.650	.920	.058
	11	3.670*	.798	.044
	12	3.934*	.714	.031
	13	4.033*	.511	.016
	14	3.972*	.577	.020

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Discussion and Conclusions

Attachments bonded to the tooth surface help for specific tooth movement facilitation and aligner retention (Bouchez, 2019). Previous studies have evaluated retention of clear aligner based on shapes and positions of attachments, and clear aligner material, thickness, and margin design. Incisal 1/3 position attachments provided the least retention. For middle 1/3 and gingival 1/3 position attachments, vertical rectangular shape showed more retentive force than horizontal beveled occlusally shape and horizontal beveled gingivally shape, respectively (Jones et al., 2009). Without attachment, Essix ACE 0.35-inch thickness material showed the highest minimum pull out force. Horizontal beveled occlusally attachment provided more retention than ellipsoid attachment and no attachment, respectively (Dasy et al., 2015). A clear aligner with 2 mm above gingival zenith-straight margin design provided more retention than that with scallop margin along the marginal gingiva one (Cowley et al., 2012).

Optical and mechanical properties should be considered in the selection of material used for making attachments. Their color and translucency should blend with the tooth to optimize esthetics. They should have dimensional stability and enough wear resistance because their shape and position affect the retentive force and ability to produce the correct force system. The material of choice usually depends on the clinician's preference. There was a study showed that the surface texture of attachments made of Amelogen Plus (Ultradent Products Inc., U.S.), a micro-hybrid resin composite, underwent greater change than that of Filtek™ Z350XT Universal (3M ESPE Dental Products, U.S.), a nano-filled resin composite, without significant shape change in both groups after six months of Invisalign treatment® (Barreda et al., 2017). The mechanical and physical properties of flowable resin composite are improved as the technology advances. The wear of some flowable resin composites is not significantly different from that of nanofilled resin composites (Shinkai et al., 2016; Sumino et al., 2013). For example, Majesty LV (Kuraray Noritake Dental, Japan), Estelite Flow Quick (Tokuyama Dental, Japan), MI Fil (GC, Japan), and Beautifil Flow Plus F00 (Shofu, Japan) had similar three- and two-body wear values to Clearfil Majesty (Kuraray Noritake Dental) (Shinkai et al., 2016). Tetric N-Flow (Ivoclar Vivadent AG, Liechtenstein) is a nano-hybrid flowable resin composite that contains 36 wt.% dimethacrylates (including TEGDMA), 63 wt.% (39 vol. %) filler particles of 40-3000 nm (barium glass, ytterbium trifluoride, highly dispersed silica, and mixed oxide) and 1 wt.% initiators, stabilizers, and pigments. Our study chose flowable composite to make clear aligner attachments because the injection method can be a better control for filling of material to the attachment window areas of the template and Tetric N-flow has the same properties as Tetric EvoFlow which was suggested for attachment built-up by Bouchez, 2019.

There are many commercially available materials for making orthodontic clear aligners and retainers. For example, Duran (Scheu Dental, Iserlohn, Germany) and eCligner (eCligner, Korea) are Polyethylene terephthalate glycol plastic; Essix A+ (Dentsply Raintree Essix, U.S.) and Essix ACE (Dentsply Raintree Essix, U.S.) are co-polyester of polyethylene terephthalate material; and Essix C+ (Dentsply Raintree Essix, U.S.) is polypropylene plastic. Different material constituents and plastic thickness have different mechanical properties. After thermoforming, Knoop hardness values of 0.75-mm eCligner and 1-mm Duran were not different but higher than that of 1-mm Essix A+ and 1-mm Essix ACE (Ryu et al., 2018). Orthodontic retainer made of polyethylene polymer exhibited less wear than the polypropylene one (Gardner et al., 2003; Raja et al., 2014). Essix ACE (Dentsply Sirona Orthodontics, U.S.) is primarily used for making retainer and aligner in non-bruxer with an average life of 18-24 months. Our study vacuumly formed the aligners using Biostar® thermoforming machine (Scheu Dental Technology, Germany) as per manufacturing code of 123 with .035"-thick Essix ACE sheet (Dentsply Sirona Orthodontics, U.S.) to avoid overheating and inconsistency during the process.

Currently, there are lots of orthodontic clear aligner companies. A protocol for an aligner wear schedule of some company, such as ClearCorrent (Institut Straumann AG, Switzerland), is 22 hours per day for 2 weeks. We assumed that patients remove and insert aligner 3 times a day for eating and brushing. Therefore, our study evaluated retention of aligner removal for 42 cycles and three consecutive retentive forces were calculated as mean retention of each consecutive day for 14 days.

After 14 days of insertion and removal of the aligner for 42 cycles, the aligner area gingival to the attachment was stretched (Fig. 3). Apart from reduced retention, this can negatively affect the extrusive tooth movement, the force system in which the active surface of the attachment is the gingival surface. Our study found that the mean retention significantly dropped after the first day. Therefore, we can inform patients that aligner removal on the first day would be more difficult than that on the subsequent days. However, this study was done in the laboratory setting which was not the same as the real clinical situation.

Firstly, in the clinical situation, the edge of the aligner is lifted by fingernails over the attachment. The aligner and attachment surface would have less contact and may lead to less wear while aligner removal than those in the laboratory setting by the universal testing machine in which the aligner was pulled perpendicularly to the occlusal plane. Secondly, intraoral aging led to changes in molecular, morphological, and mechanical properties of thermoplastic vacuum-form material (Ahn et al., 2015). Thirdly, various cleaning solutions and cleaning methods decreased the flexural modulus of Essix ACE material (Wible et al., 2019). Lastly, tooth movement force occurs when the aligner is actively fit on the teeth and attachments. Though in our research, the aligner was fit passively.

In conclusion, the mean retentive force of aligner removal of the first day was significantly higher than those of the subsequent days. The aligner area gingival to the attachments was stretched, which may be the reason for retentive force reduction. However, the attachments were not visibly worn away after 14 days of insertion and removal for a total of 42 cycles.

The sample size of this study was small (N = 3) as it was a pilot study to identify the feasibility, test the study protocol and explore the potential outcome. The data can be used for a further study with larger sample size or an *in vivo* experiment to confirm the result of this study. There are other variables that affect aligner retention, such as attachment size, tooth shape, tooth alignment and amount of tooth movement in each stage. Further study may include the retentive force of several aligners per a dental model, the wear of attachment and aligner related to aligner insertion and removal, and tooth movement related to the fit between the aligner and active surface of attachment.

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