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Retention of Different Orthodontic Aligners According to their Thickness and the Presence of Attachments

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ABSTRACT

Objectives: *This study was aimed to compare the retention among 3 types of orthodontic aligners according to their thickness and according to the presence of beveled attachments.* ***Materials and methods:*** *An impression was taken for the upper arch of a patient, poured with die stone and scanned using CS 3600 intraoral scanner. The treatment plan was done using blue sky plan software and 6 models with attachments and 6 without attachments were exported. The first two models of each group were printed using Micro play 3D printer, and 3 thermoplastic materials were used in this study. Total 10 samples for each material were thermoformed over each of the 4 printed casts to make aligners. Retention tests were done on the 2 original models; one with the attachment and another without the attachment using the tensile test in the universal testing machine to measure the maximum forces required to remove the aligner from the model.* ***Results:*** *Leone 0.8 mm was higher than clear aligner (0.5 mm) in the retention tests of all the groups. Leone (0.8 mm) was higher than Duran (1 mm) in 2 groups (aligner number 1 groups). The presence of attachments led to an increase in the retention means of all the 3 brands when compared to the non-attachments group.* ***Conclusion:*** *Clear aligner (0.5 mm) is the least retentive aligner. Leone (0.8 mm) has the highest retention value in both attachments and non-attachments groups regarding aligner number 1. Adding beveled attachments lead to the significant increase in the retention of all aligners regarding the aligner number 1.*

Keywords: Retention, Aligner, Attachments, Orthodontic, Leone, Duran, Tensile, Thermoplastic

INTRODUCTION

The idea of moving the teeth using clear thermoplastic material was started by Kesling who used the positioner in minor tooth movement [1]. Many orthodontists had followed Kesling in his thought and tried to make better appliances. However, the appliances they produced were limited to simple tooth movement and were inferior to edgewise appliance regarding the convenience of use. In 1999, Align Technology developed the Invisalign system which allows for more complex tooth movement using clear thermoplastic appliances produced from casts that were produced by using CAD-CAM [2,3].

Thermoplastic materials are excellent in aesthetic appearance, easy to be formed and simple to use. However, investigations and researches on aligners are very limited and their scientific features are not well studied. Many companies have designed aligners with different properties. Invisalign (Align Technology, San Jose, California) uses the same aligner material throughout the treatment and scalloped design of the aligner margins. Clear-aligner (Scheu Dental, Iserlohn, Germany) uses aligners in 3 thicknesses 0.5 mm, 0.625 mm, and 0.75 mm) [4]. In addition, different attachment designs were available by different companies in order to improve the aligner retention and enable the aligner to perform complex tooth movements like rotation movement [5]. In addition to the aligner material properties, retention is very important to produce the desired tooth movement. Unlike fixed orthodontic appliance which is fixed to the teeth, the orthodontic aligner is removable and its effectiveness depends mainly on how fit and retentive is the aligner in the patient mouth [6]. For this reason, this study compares the retentive properties of 3 aligner's brands with and without attachments to find the suitable material for best aligner retention and consequently best aligner action. It is worth to mention that this study is the first study that measures aligner retention using active aligners, the first study that uses Blue sky plan for an orthodontic treatment plan in research purpose, the first study that measures more than one step aligners in retention tests (Figure 1).

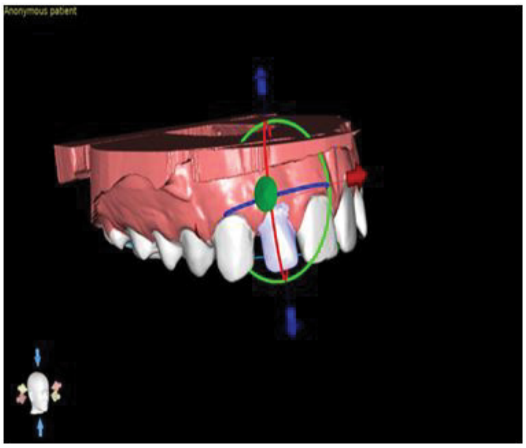

Figure 1 Teeth movement step from the facial view using Blue sky plan software

PATIENTS AND METHODS

An impression was taken to the upper arch of a student who agreed to be the subject of the study. He had rotated left lateral incisor overlapped over the left central incisor which was ideal for the study because we can make aligners that will move the laterals by tipping, bodily and rotational movements. The impression was taken by using additional silicon impression material (Vinyl polysiloxanes) and was poured with a stone type IV (die stone). The process of orthodontic treatment planning till aligner fabrication was described by Hilliard (Hilliard, 2008). The model was scanned using Carestream Dental's CS 3600 intraoral scanner (Carestream, Canada). The advantages of using a scanner to the cast instead of the jaw are ease of access, the range of movements permitted which allow for capturing of undercuts and areas of complex contacts [7]. After completion, the scanned cast was saved and a file in STL (Standard Triangle Language) format was produced. The STL format digital model was imported in Blue sky plan, software specialized in the orthodontic treatment plan and this software produces a series of virtual casts (in STL format) and each cast represents a stage of treatment. In the present study, the goal was to correct the rotation of both laterals as 2 cases; one with attachments and another without the attachment; then exporting the number of casts that would be needed to complete this goal. The specifications of the attachment were to use rectangular attachments beveled towards the occlusal surface with dimensions (height: 2 mm, width: 3 mm, depth: 0.25 mm incisally and 1.25 mm gingivally), and to put these attachment on both premolars and in both sides of the arch (Figure 2) [7].

Figure 2 preparing the Biostar machine for the thermoforming process with the model centered on the working bench of the machine

Finally, the models were exported and ready to be printed. The 3D printing was done using the Micro play dental 3D printer (Micro play, Spain). The models that had been printed were:

- The original model without attachments

- The Original model with attachments
- The cast number 1 with attachment
- The cast number 1 without attachment
- The cast number 2 without attachment
- The cast number 2 with attachment

The aligners were made using the Biostar machine of Scheu dental company from 3 types of thermoplastic materials (Leone, Duran, CA® Clear aligner). The aligner were cut in a way that edges were 2 mm from the gingival margins and were straight to ensure the best aligner retention [8].

Two models were used, the normal model without attachments and the model with attachments. These models were modified by drilling holes (3 mm in diameter, 5 mm in depth) in the occlusal surfaces of the first molars at the junction of the mesiolingual edge and the central fissure [6]. These holes allow for the placement of a metal stop attached to a steel rod. In order to provide a vertical pull of the aligner, these rods should pass from the molar holes through the aligner and continue to the measurement machine. The metal stop at the end of the rod did not interfere with the perimeter of the molar hole, preventing any possible friction that could affect the test results. The stop also did not interrupt the normal anatomy of the molar, ensuring that aligner would cover the teeth in its original thermoformed shape [6]. The tensile test was used to apply vertical forces that pull the aligner from the model. Measurements were made with a Universal Testing Machine (Laryee Technology Co, China) by recording the maximum force required to remove the aligner from the model (Figure 3).

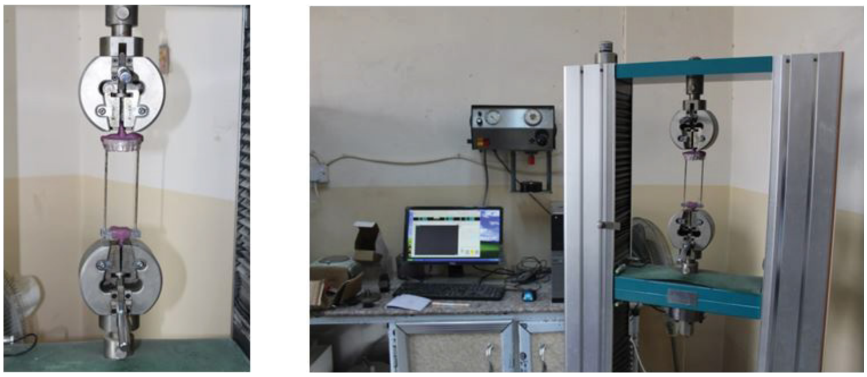

Figure 3 testing the retention of the aligners using Universal Testing Machine

In order to avoid shearing forces during the perpendicular removal forces, a bolting apparatus was fabricated to ensure perpendicular connection of the steel rods from the teeth to the testing machine [6]. Vertical displacement forces were applied at a rate of 6.35 mm/minute and measured in Newton. The tests were done 3 times for each of the 120 sample (60 samples with attachment and 60 without) for a total of 360 tests [8]. The data were analyzed using SPSS (Statistical package of social science version 24, IBM Co., New York, USA). The statistical analyses included descriptive statistics and inferential statistics. One-way ANOVA test was followed by post-hoc Tukey's test for comparing retention, and finally independent sample t-test for comparing the retention between aligners with and without attachments.

In the statistical evaluation, the following levels of significance were used:

- $p>0.05$: Non-significant
- $0.05 \geq p>0.01$: Significant
- $p \leq 0.01$: Highly significant

RESULTS

For aligner number 1, the mean forces required to remove the aligner number 1 from the cast with attachment ranged between 21.33 N to 27.67 N for clear aligner (0.5 mm), between 47.67 N to 52.00 N for Leone (0.8 mm) and between 42.00 N to 45.67 N for Duran (1 mm) The mean forces required to remove the aligner number 1 from the cast without attachment ranged between 15.33 N to 17.33 N for clear aligner (0.5 mm), between 34.0 N to 39.67 N for Leone (0.8 mm) and between 31.67 N to 36.67 N for Duran (1 mm).

For aligner number 2, the mean forces required to remove the aligner number 2 from the cast with attachment ranged between 20.67 N to 24.67 N for clear aligner (0.5 mm), between 31.00 N to 37.67 N for Leone (0.8 mm) and between 34.00 N to 39.33 N for Duran (1 mm).

The mean forces required to remove the aligner number 2 from the cast without attachment ranged between 18.33 N to 22.00 N for clear aligner (0.5 mm), between 43.33 N to 50.33 N for Leone (0.8 mm) and between 45.33 N to 49.33 N for Duran (1 mm). One-way ANOVA table used to compare the retention among different types of aligners showed significant difference with all tested groups (Table 1).

Table 1 One-way ANOVA table compare the retention among different types of aligners

Aligners	ANOVA	Sum of Squares	d.f.	Mean Square	F-test	p-value
Aligner with Attachment Number 1	Between Groups	3520.920	2	1760.460	717.405	0.000
	Within Groups	66.256	27	2.454		
	Total	3587.176	29	-		
Aligner with Attachment Number 2	Between Groups	1083.161	2	541.580	176.474	0.000
	Within Groups	82.860	27	3.069		
	Total	1166.021	29	-		
Aligner without Attachment Number 1	Between Groups	2595.560	2	1297.780	551.016	0.000
	Within Groups	63.592	27	2.355		
	Total	2659.152	29	-		
Aligner without Attachment Number 2	Between Groups	4980.619	2	2490.310	863.376	0.000
	Within Groups	77.878	27	2.884		
	Total	5058.498	29	-		

Tukey honestly significant difference (HSD) was used after ANOVA to compare among the aligners within one group to find means that are significantly different from each other and found that there was a significant difference between clear aligner (0.5 mm) and Leone (0.8 mm) in all groups with higher retention means for Leone in all situations. There was a significant difference between clear aligner (0.5 mm) and Duran (1 mm) in all groups with higher retention means for Duran in all situations (Table 2).

Table 2 Tukey HSD after ANOVA

Aligners		Aligner with Attachment Number 1		Aligner with Attachment Number 2		Aligner without Attachment Number 1		Aligner without Attachment Number 2	
		Mean Difference	p-value	Mean Difference	p-value	Mean Difference	p-value	Mean Difference	p-value
Clear aligner (0.5 mm)	Leone (0.8 mm)	-25.366	0.000	-11.334	0.000	-20.969	0.000	-27.332	0.000
	Duran (1 mm)	-19.433	0.000	-13.799	0.000	-18.202	0.000	-27.334	0.000
Leone (0.8 mm)	Duran (1 mm)	5.933	0.000	-2.465	0.011	2.767	0.001	-0.002	1.000

There was a significant difference between Leone (0.8 mm) and Duran (1 mm) except one situation which was the aligner number 2 without attachments where there was no significant difference between Duran and Leone. A t-test was used to compare the retention of different aligner companies according to the presence or absence of the attachments. The test showed that aligners are significantly more retentive in the presence of attachments except for the aligner number 2 in case of Leone and Duran which showed higher retention when the attachments were not present (Table 3).

Table 3 Comparing the retention among different types of aligners according to the presence of attachments

Types of aligners	Descriptive statistics				Comparison (d.f.=18)	
	With attachment		Without attachment			
	Mean	S.D.	Mean	S.D.	t-test	p-value
Clear aligner (0.5 mm)	24.267	1.925	16.199	0.863	12.091	0.000
Leone (0.8 mm)	49.633	1.365	37.168	1.847	17.160	0.000
Duran (1 mm)	43.700	1.338	34.401	1.705	13.566	0.000
Clear aligner (0.5 mm)	22.434	1.277	20.200	0.996	4.363	0.000
Leone (0.8 mm)	33.768	2.037	47.532	2.399	-13.831	0.000
Duran (1 mm)	36.233	1.852	47.534	1.380	-15.474	0.000

DISCUSSION

In order to simulate the actual orthodontic aligner cases, an impression for a patient with misalignment was taken and poured using die stone material. Taking an impression for a human jaw was done previously by Dasy, et al., [6]. However, they did not correct misalignment to produce active aligners but they created passive aligners and tested them for retention. On the other hand, Cowley, et al., used a Kilgore typodont tooth and an impression was taken for these teeth and also aligners were made on this cast without teeth movements (passive aligners) [8]. The primary concern for this study was to control the variables that could affect the trial. This was done by using the same material type which was Polyethylenterephthalat-Glycol Copolyester (PET-G), following the manufacturer's instructions for heating time, cooling time and pressure magnitude, using one model for fabrication of the aligners and making attachments on the same model to prevent the difference that could happen when using two models. Printing with one 3D printer would eliminate the differences of using more than one printer. Trimming all aligners with the same design could prevent the individual differences that may affect the results of the trial. Two variables would be discussed to draw a conclusion about the aligner retention and these are material thickness and the presence of the attachments.

Aligner Material Thickness

Leone (0.8 mm) was higher than clear aligner (0.5 mm) in all tested groups and was higher than Duran (1 mm) in two groups (aligner number 1 groups) and equals to it in one group. This means that the material thickness is not the only factor that affects the retention of aligners. This is in line with Hahn, et al., and Dasy, et al., [6,9]. This study was done so that all variables are constant and all aligners made from the same material, therefore, the amount of movement done on each step is a critical factor that can affect retention.

In aligner number 1, clear aligner (0.5 mm) and Leone (0.8 mm) fitted more to the model when compared to the Duran (1 mm) and this explains why Leone was higher than Duran in retention tests. However, it is the material stiffness that allows Duran to hold firmly to the cast and made its retention force higher than clear aligner (0.5 mm) (Figure 4).

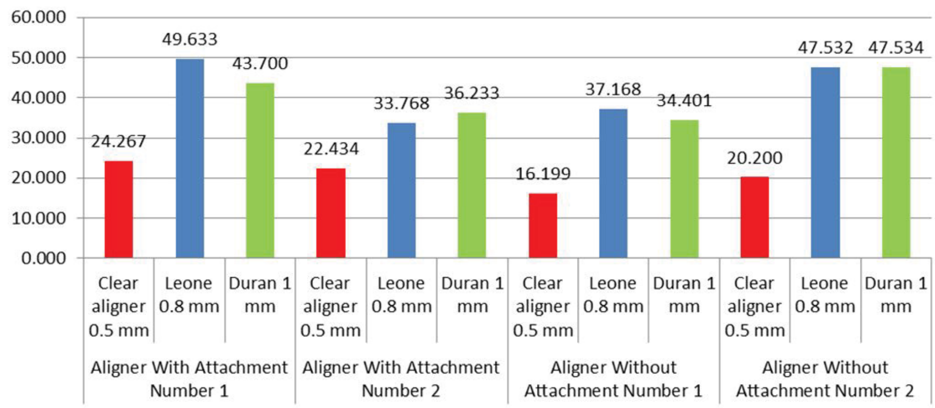

Figure 4 Retention tests of the different aligner

In aligner number 2, more aligner deflection would be expected due to higher forces that would be applied from the aligner to the model. Despite the fact that they were less fitted than aligner number 1, all aligners were stuck firmly into the models when seated and needed more forces to remove them from the model. This can explain why the retention means of the aligners 2 were higher than those of aligner 1 in the non-attachment groups. Higher retention means of 1 mm sheets over the 0.5 mm sheets coincide with the findings of Dasy, et al., [6].

Presence of the Attachments

The presence of attachments led to an increase in the retention means of all the 3 brands when compared to the non-attachment group. However, this effect was effective on the aligner 1 group only because these aligners were fitted over the models perfectly and the addition of aligners made their fitness more secure. This can explain the increase in the retention of these aligners.

On the other hand, aligner 2 groups which were less fitted because of the larger tooth movement became more deflected by the presence of attachments. As the aligners are fitted anteriorly and deflected posteriorly, adding attachments posteriorly would lead to more deflection. This explains why aligner 2 in attachments groups were less retentive than those of non-attachments groups. Clear aligner (0.5 mm) can be excluded as it is the least deflected among aligners and the most fitted on the models and adding attachments would help to increase its retentions.

Increasing the retention of aligner after addition of attachments coincides with the results of Dasy, et al., and with the findings of Cowley, et al., [6,8]. Therefore, adding attachments should be considered when there are mild forces and less retentive material.

CONCLUSION

- Clear aligner (0.5 mm) is the least retentive aligner
- Leone (0.8 mm) has the highest retention value in both attachments and non-attachments groups regarding aligner number 1
- Adding beveled attachments lead to a significant increase in the retention of all aligners regarding aligner number 1
- Adding beveled attachments lead to a decrease in the retention of aligners regarding aligner number 2 with the exception of the clear aligner (0.5 mm)

DECLARATIONS

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Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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