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Comparison of Retention Between Two Aligner Products Before and After Thermocycling

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ABSTRACT

The use of clear orthodontic aligners has increased as an alternative to conventional braces. Therefore, knowledge about the characteristics of the aligner materials can help to provide more accurate treatment results and give orthodontists who are utilizing or planning to employ this technology more information about their behaviour. This study aimed to investigate and compare the effect of thermocycling on the retention measurement of two aligner products used in the fabrication of orthodontic aligners. Two thermoplastic products of Duran® 0.75 mm and Erkodur® 1 mm were used in this study. Digital impressions were obtained for the upper and lower arches of 10 patients. Digital models with two rectangular attachments in the first and second premolars were constructed by using blue sky plan software. After the construction of orthodontic aligners, retention tests were measured using a tensile test with a universal testing machine to measure the maximum forces required to remove the aligners from the models. Twenty aligners were fabricated for each type of product, and measurements were conducted before and after thermocycling. Duran® upper aligners retention showed no significant changes in comparison with Erkodur®, however, Duran® lower aligners showed significant changes in comparison with Erkodur® before thermocycling. However, Duran® aligners showed no significant change, whereas, Erkodur® in both upper and lower arches showed a significant decrease in retention after thermocycling. The retention of the Duran® aligner is higher than that of Erkodur® and thermocycling decreased the retention of the aligners fabricated from Erkodur® in comparison with Duran® aligners.

1. Introduction

Social life now a day strongly depends on one's smile and dental health. Because of this, more patients are seeking aesthetically pleasing orthodontic treatment. Manufacturers began reducing the shape of metal brackets and offering tooth-coloured ceramic brackets in addition to invisible® or lingual brackets to satisfy this demand [1]. This has caused a significant and rapidly developing upset with the aesthetic orthodontic equipment. Given that it is nearly invisible and removable, a transparent aligner is one of the most exciting appliances for the patient. As a result, the teeth won't be damaged as much by caries, calculus, or the white spots that are generally associated with fixed orthodontic therapy [2]. Clinicians and aligner manufacturers work to improve an aligner's retention by employing thicker material, retention attachments, and lengthening the aligner's margin over the gingiva.

There hasn't been any research done yet to show which aligner material and design works best for retention when used with various attachment forms [3]. To improve aligner retention and enable the aligner to carry out complex tooth movements like rotation, different attachment types of several firms have unique connection plans available [4]. Understanding the characteristics of the aligner materials and designs can help offer more accurate results from the aligners and provide more information to an orthodontist who is currently using or planning to use this innovation [5].

Thermocycling, which has been widely used in dental research, involves repeatedly submerging things in distilled water at different temperatures to speed up material ag[eing] [5]. Resin polymers are not inert and are subject to alteration when subjected to heat, humidity, continuous pressures, and saliva in the oral environment [6]. It makes it obvious that any deterioration of aligner materials, whether during or after production [7]. or after exposure to the oral environment [8], would limit their effectiveness, which would lead to less predictable tooth movements [9]. Digital technology was used to create several types of aligners, and imprints are taken to enable the creation of an accurate cast that can be scanned to create a virtual 3D model [1]. The dentist can then alter this 3D model and using specially developed software, the malocclusion is digitally rectified. A series of transparent plastic aligners can then be created using it to continuously correct thermal occlusion.

The fact that clear aligners are removable, that they may be sequentially adjusted to patients' unique malocclusion configurations, and that they can gradually guide teeth into their predetermined positions all make them extremely useful. Modern dental materials are continually being updated, but they are not all created equal. The ones that are now on the market differ in terms of construction materials, thickness, and therapeutic regimen. Therefore, it is necessary to screen and evaluate materials' properties fast and effectively, moreover, It is necessary to predict the ageing process of materials in the mouth in order to quickly determine a material's utility and longevity.

Different kinds of transparent aligner materials are now used, according to the literature. Additionally, popular thermoplastic materials available on the market are typically used for aligners rather than retainers. Therefore, it is crucial to research the distinctive features of materials and how they react to various stressors in order to enhance the effectiveness of the various aligner materials in orthodontic therapy. To improve the efficacy of aligners, and to introduce a better material that exhibits more effective properties.

To the best of the researcher's knowledge, there is no evidence available information about the impact of thermocycling on the retention behaviour of orthodontic aligners made of Erkodur® and Duran® materials. Thus this study aimed to evaluate and compare the effects of thermocycling on the retention of orthodontic aligners made from two different products. The sty hypothesized that there is a significant difference in the retention of orthodontic aligners fabricated from two different products before and after thermocycling.

2. Material and Method

The necessary ethical clearance was obtained from the College of Dentistry, University of Mosul (UoM.Dent/H.DM.47/22). The digital impressions were taken to the upper and lower arches of the participants by using an intra-oral scanner 3Disc heron, USA. Inclusion criteria were as follows; crowding or spacing (1- 5mm), rotations that are 20 degrees or less and tipping at an angle below 45°. The amount of tipping, rotations and crowding were detected by blue sky plan software. The advantages of using digital scanning were to reduce time and simplify clinical procedures. It eliminates the problems of cast storage or breakage and reduces the discomfort feeling of the patient when taking an impression [10]. After completion, the scanned images were saved in an STL (Standard Triangle Language) format file. The digital model was imported into Blue sky plan software that produced casts (in STL format), and then the rectangular attachments were placed in the first and second premolar areas on both sides (Figure 1).

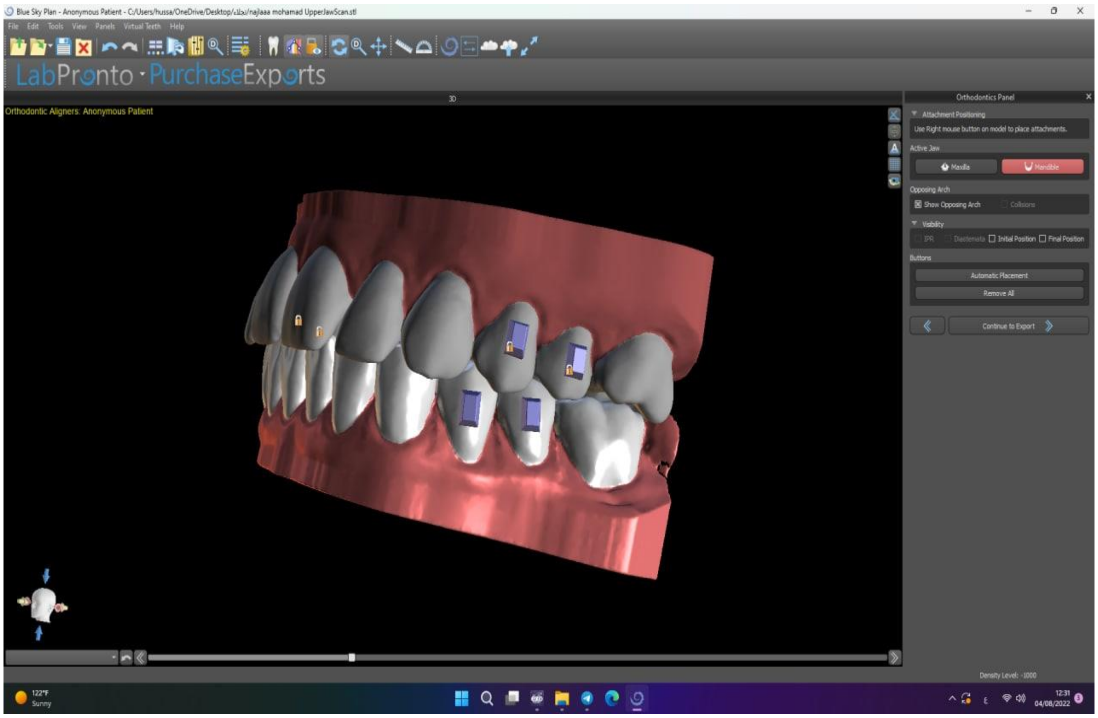

Figure 1. Attachment in first and second premolar by using Blue sky plan software

Finally, the models were exported and ready to be printed. The 3D printing was done using the sprint Ray pro95 dental 3D printer (SprintRay pro95, USA). The aligners were made using the Ministar® machine (SCHEU-DENTAL GmbH\ Germany Am Burgberg 2058642 Iserlohn) from 2 types of thermoplastic materials (Dura® and Erkodur®). The aligners were cut in a way that the edges were 2 mm from the gingival margins and were straight to ensure the best aligner retention [11].

Thermocycling Process: In this study, after thermoforming each sample, the thermocycling process was conducted. Thermocycling was used in this study to simulate temperature changes in the oral environment. The consideration is that patients should use each aligner at least 22 h per day for two weeks .in this study 14 thermal cycle was chosen to represent the wearing for each day so and 200 cycles were chosen to cover the 2 weeks to maximize the simulation with oral conditions [9]. Before thermocycling, a sample was immersed in 37°C distilled water for 24 h, and then, thermal cycles that included 5°C for the 20s, and 55°C for the 20s, with a transfer time of 12s were exerted in distilled water via a thermocycling machine. Then, they were stored in distilled water in an incubator (Pars Azma Co, Tehran, Iran) until the time of analysis [9], [12].

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 mesio-lingual edge and the central fissure [13]. These holes enable the insertion of a steel rod and a metal stop. These rods should travel from the molar holes through the aligner and onto the measurement device in order to generate a vertical pull on the aligner. The metal stop at the end of the rod did not obstruct the molar hole's perimeter, preventing any potential friction that would have impacted the test's outcomes. Additionally, the stop did not alter the molar's regular architecture, improving that the aligner would cover the teeth in its initial thermoformed shape [13].

The tensile test was used to apply vertical forces that pull the aligner from the model. Measurements were made with a universal testing machine (Tinius Olsen, England) by recording the maximum force required to remove the aligner from the model (Figure 2).

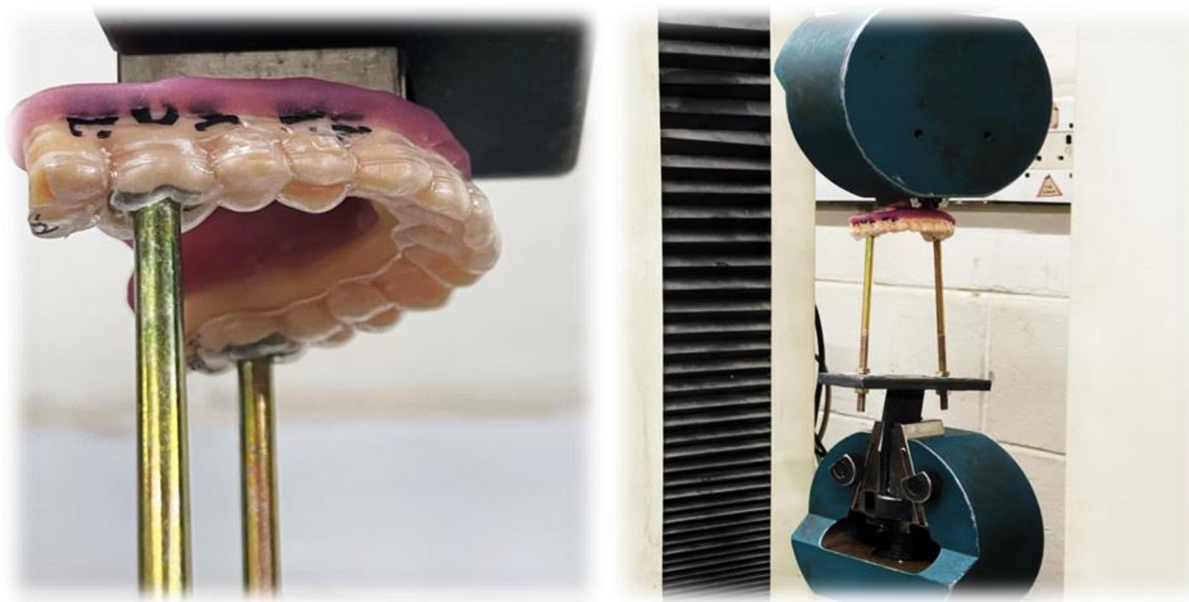

Figure 2. Testing the retention of the aligners using a Universal Testing Machine

Locking equipment was created to assure the perpendicular connection of the steel rods from the teeth to the testing machine in order to prevent shearing forces during the perpendicular removal forces [13]. Vertical displacement forces were applied at a rate of 6.35 mm/minute and measured in Newton. The tests were done 2 times (before and after thermocycling) for each of the 20 samples.

3. Results

A normality test: The test was done to assess the normality of data distribution of the aligner retention of different study groups. The test explained that the data were normally distributed except lower arch for Erkodur® groups after thermocycling and the upper arch for Duran® groups after thermocycling as shown in table 1.

Table 1. Assessment of the normality of data distribution of the aligner retention measurement

Variable	Statistic	*p*-value
Upper arch for Erkodur® before thermocycling	0.185	0.200
Upper arch for Erkodur® after theromcycling	0.214	0.200
Lower arch for Erkodur® before thermocycling	0.225	0.163
Lower arch for Erkodur® after theromcycling	0.288	0.018*
Upper arch for Duran® before thermocycling	0.163	0.200
Upper arch for Duran® after theromcycling	0.344	0.001*

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Lower arch for Duran® before thermocycling	0.253	0.069
Lower arch for Duran® after theromcycling	0.165	0.200

*Significant at $p<0.05$
Measurements are in Newton.

The means and standard deviation (SD) of the aligner retention test of samples for the sturdy groups were presented in table 2. The highest mean value was recorded regarding retention of the upper arches (43.09 ±7.73) in Duran® groups after thermocycling, whereas the lowest mean value was 28.96 (14.28±) for Erkodur® after thermocycling. The highest mean value regarding aligner retention of the lower arches was 43.50 (3.87±) in Duran® before thermocycling, whereas, the lowest mean value was 34.64 (4.65±) in Erkodur® after thermocycling.

Table 2. Descriptive statistics for retention measurements

Variable	Mean±SD	Minimum-Maximum
Upper arch for Erkodur® before thermocycling	35.59±11.26	16.3-50
Upper arch for Erkodur® after theromcycling	28.96±14.28	10.1-48.7
Lower arch for Erkodur® before thermocycling	39.67±3.45	31.67-44.1
Lower arch for Erkodur® after theromcycling	34.64±4.65	30.01-44.02
Upper arch for Duran® before thermocycling	41.22±11.67	22.1-60.1
Upper arch for Duran® after theromcycling	43.09±7.73	33.7-56
Lower arch for Duran® before thermocycling	43.50±3.87	34.33-47.61
Lower arch for Duran® after theromcycling	42.81±3.94	35-48.5

Measurements are in Newton.

Results have shown that there was a statistically significant difference between the aligner retention of upper arch Erkodur® before and after theromcycling. Also, there was a statistically significant difference in the retention between lower arch Erkodur® before and after theromcycling as shown in table 3.

Table 3. Comparisons of retention measurement between same groups (Druan®) and (Erkodur®)

Pairwise comparisons	**T value**	***p*-value**
upper arch for Duran® Vs. upper retention Duran® after theromcycling	0.87	0.402
upper arch Erkodur® Vs. upper retention Erkodur® after theromcycling	3.64	0.005*
Lower arch for Duran® before thermocycling Vs. Duran® after theromcycling	1.62	0.139
Lower arch Erkodur® before thermocycling Vs. Erkodur® after theromcycling	4.31	0.002*

*Significant at $p<0.05$
Measurements are in Newton.

Comparisons of aligner retention measurement before and after theromcycling for each product in the upper and lower. Results have shown that there was a statistically significant difference in the aligner retention measurement between the upper arch of Erkodur® and the upper arch of Duran® after thermocycling. Moreover, a statistically significant difference in the retention measurement between the Lower arch of Erkodur and Duran® before and after thermocycling was recorded as shown in table 4.

Table 4. Comparisons of retention measurement between Duran® and Erkodur®

Variable	**t- value**	***p*-value**
upper arch for Erkodur Vs. upper arch for Duran before thermocycling	1.06	0.874
upper arch for Erkodur Vs. upper arch for Duran after thermocycling	2.75	0.006*
Lower arch for Erkodur Vs. Duran before thermocycling	2.33	0.032*

Variable	t- value	*p*-value
upper arch for Erkodur Vs. upper arch for Duran before thermocycling	1.06	0.874
upper arch for Erkodur Vs. upper arch for Duran after thermocycling	2.75	0.006*
Lower arch for Erkodur Vs. Duran before thermocycling	2.33	0.032*
Lower arch for ErkodurVs. Duran after thermocycling	4.24	0.001*
*Significant at $p<0.05$		

4. DISCUSSION

Retention is very important to produce the desired tooth movement. Unlike fixed orthodontic appliances, the orthodontic aligner's effectiveness depends mainly on how fit and retentive is the aligner in the patient's mouth. Moreover, [9] considered the retention of the teeth as one of the un-quantified features of aligners which is crucial to induce tooth movement. The current study analyzed and compared aligner materials from two different manufacturers to ascertain the mechanical properties that would create the highest aligner action.

In this investigation same kind of material, Polyethylenterephthalat-Glycol Copolyester (PET-G) was used. Additionally, the manufacturer's recommendations for pressure magnitude, heating, and cooling were rigorously followed. The same model that was used to create the aligners was utilized to create the attachments for the first and second premolars. The printing was done using the same 3D printer to get rid of the variances brought on by utilizing more than one. To prevent individual variances that could have an impact on the study's findings, all aligners were cut in the same way.

In our study, 40 samples for the retentions test were used (20 for upper and 20 for lower arches before and after thermocycling), [11] used 10 samples, each sample was tested three times and average of the 30 tests was considered to be the representative for the retention test. It is worth mentioning that our study is the first that used upper and lower arches to measure the retentions of aligners constructed from Duran® and Erkodur®.

To simulate the actual orthodontic aligner cases, digital impression of patients with specific features of mal-alignment was taken by an intraoral scanner, this was similar to [14], [15], who considered the digital impressions rather than the direct impression of a human jaw. Moreover, to increase the retention of aligners, rectangular and attachments were chosen as a better choice for this purpose [9]. Several authors used a rectangular attachment to enhance retentions [13], [16]. Moreover, one step of tooth movement was considered to produce aligners tested for retention [17]. The goal of thermocycling was to mimic any potential effects of abrupt intraoral temperature changes [12].

The treatment plan utilized in the current trial was created to simulate the worst-case scenario of massive intraoral temperature changes brought on by having food and drinks whilst wearing aligners for a maximum amount of time. In a study by [12] the thermal and mechanical qualities of the aligner are decreased by temperature fluctuations that may be brought on by consuming food and beverages while wearing the aligner. After 200 thermocycling cycles, a different investigation by [9] found that Duran® had more thermal and mechanical stability than Erkodur®.

Thermocycling was performed in the current study in order to maximize the simulation with oral circumstances. using a temperature aging machine, thermal cycles involving 5°C for the 20s, 55°C for the 20s, and a transfer period of 12s were applied in the distilled water [9]. [18] claimed that the hardness of different aligners, such as Duran®, does not change significantly after 500 thermocyclers but significantly

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decreases after 2500 cycles. Since the aligner is frequently used for about 2 weeks, the researcher used 200 thermal cycles, which did not lead to changes in the hardness of Duran®.

The result of the current study showed that the retention of the Duran® group is higher than Erkodur® before and after thermocycling. This can be explained by the material of Duran® that allows it to hold firmly to the cast and made its retention force higher than Erkodur® material. Or, may be due to thermocycling procedures that make a change in the molecular structure of the Erkodur® aligner material which reduces the thermal and mechanical properties [5]. Moreover, this study showed a decrease in retentions of Erkodur® groups after thermocycling, this can be explained by the change in the thermal and mechanical properties of the sheet after the thermocycling process.

According to the best knowledge of the researcher, this is the first study that compares the Duran® and Erkodur® aligner retention in the upper and lower dental arches. Higher retention means 0.75mm sheets over the 1mm sheets. This result generally coincides with the findings of [13] who used Clear-Aligner® (Scheu Dental) with different thicknesses (0.5 mm,0.625 mm, 0.75 mm), and Essix ACE 0.76 mm. CA 0.65 mm and CA-0.75 mm showed a greater amount of retention in comparison with the 0.5 mm. Moreover, they recorded that the Clear-Aligner® hard and Essix ACE which have approximately the same thickness, but, different compositions of the materials showed a difference in retention between Essix ACE 0.75 and Clear-Aligner® 0.76 mm with attachment. They suggested that retention depends on material composition and does not necessarily correlate with material thickness.

A previous study by [17] evaluated the retentions of aligners between 0.8mm,0.5 mm, and 1mm was found that 0.8 has higher retention than others. They suggested that the greater thickness of the material is not necessarily equivalent to better retention of the aligner, the material composition probably plays a more important role in retention [9]. However, The results of the current study disagree with [19] indicating that Duran® 1 mm has higher retention than Leone® 0.8mm.

A study by [5] indicates that the change in the temperature caused a change in the molecular structure of the sheets. The ability of the aligner material to adapt or conform to the models during the thermoforming process is an important requirement of aligner retentions. At a defined temperature of around 110 ◦C, the adaptability of polyurethane material has been found to be superior to that of other materials [20]. Thermoplastic polymers exhibit a glass transition temperature at which their rigid state transforms into a rubbery state. The glass transition temperature (T_g) is the temperature of amorphous polymers at which increased molecular mobility results in significant changes in thermal properties [21]. When the thermal properties of three commercial clear aligners (Invisalign®), Simpli5® (Allesee Orthodontic Appliances) and Clear Correct® (ClearCorrect, Round Rock) were compared, all three aligner systems were found to have a glass transition temperature above the accepted oral maximum temperature, with no significant differences observed before and after their clinical usage [22]. Below the glass transition temperature, PETG shows a more brittle mechanical behaviour, while above Tg it is rubbery [12]. Plastics solidify to glass at temperatures lower than the glass transition temperature (Tg) but soften rapidly on exceeding Tg [23].

The study limitation is that intraoral ageing was assessed through heat cycling, making it unable to analyze the impact of other factors like drink consumption or oral cleanliness on the oral environment or fatigue carried on by occlusal force loading.

5. Conclusions

The retention of the Duran® aligner is higher than that of the Erkodur® product. Thermocyclining decreased the retention of the aligners fabricated from the two products except the aligner fabricated from Duran® product for the upper arch.

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