Comparison of Frictional Resistance of Micro-Crystalline and Polycrystalline Alumina Self-Ligating Ceramic Brackets with Stainless Steel Archwire

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Abstract

The objective of this study was to compare the frictional resistance generated among various passive self-ligating ceramic brackets.

Four groups of passive self-ligating brackets, including Damon Q2 (stainless steel), Damon Clear2 (polycrystalline alumina), Truklear (polycrystalline alumina), and Clarity Ultra (micro-crystalline alumina), were tested for frictional resistance with 0.019 × 0.025-in stainless steel (SS) archwires. Five brackets from each group were attached to the teeth on the right quadrant of the maxillary stereolithographic model. Static and kinetic friction were measured on a universal testing machine. Five replicas were performed with new wires and brackets of the same group. Analysis of variance and Bonferroni Post hoc test were performed to determine whether there is a statistically significant difference between groups (p-value < 0.05).

Clarity Ultra had the significantly highest frictional force in static and kinetic friction. No significant differences were found among Damon Q2, Damon Clear2, and Truklear in the static friction test. Kinetic friction increased from Damon Clear2, Damon Q2, Truklear to Clarity Ultra. However, no significant differences were shown between Damon Clear2 versus Damon Q2 and Damon Q2 versus Truklear.

Clarity Ultra generated the highest frictional resistance in static and kinetic friction among the experimental groups. Other groups of self-ligating ceramic brackets (Damon Clear2, Truklear) generated a comparable frictional force to self-ligating stainless steel brackets (Damon Q2).

Experimental article (J Int Dent Med Res 2024; 17(1): 38-43)

Keywords: Ceramic brackets, frictional resistance, micro-crystalline alumina, self-ligating brackets.

Received date: 18 October 2023 **Accept date:** 21 December 2023

Introduction

Friction occurs inevitably from the gliding among archwire, bracket, and ligature in sliding mechanics of orthodontic tooth movement. To move the teeth, optimum force is required to overcome the resistant force from friction and to create tissue remodeling. The study reported that 12% to 16% of the orthodontic force was lost through frictional resistance.[1] The higher the resistance, the more force is needed. Excessive force can compromise the amount of tooth movement and cause anchorage loss.[2]

Several factors, such as the method of ligation[3,4], bracket design[5], wire size and alloy[6,7], and the angulation between the archwire and bracket slot, could affect the resistance force.[8] Apart from the applied load, the material's surface characteristics and coefficient of friction are considered major factors in friction.[6]

Ceramic brackets generated nearly twice as much frictional resistance as stainless steel brackets, and the rate of tooth movement decreased by 30-50% compared to metal brackets.[9] Although high resistance was generated, these brackets are still generously used because of aesthetic concerns. Compared to when they were initially introduced in the late 1980s, ceramic brackets have much-enhanced properties nowadays. For example, several modifications were applied to ceramic brackets, such as metal slot ceramic brackets and round corner slot design, to lessen frictional force.[10] Self-ligating systems are generally integrated into ceramic brackets due to the esthetic consideration and the intention to reduce frictional force. Numerous studies have shown

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that self-ligating ceramic brackets generated significantly less frictional resistance than conventional ones.[11,12]

Recently, fine-grained (micro-crystalline) alumina brackets have been introduced with improvements in bracket properties. According to manufacturers, they are more stain-resistant, have more strength, and have a better low-profile design. Previous studies showed a comparable frictional resistance of these fine-grained alumina brackets to metal slot ceramic brackets and stainless steel brackets.[12,13]

Combining a self-ligating system and the development of bracket materials diminish the use of metal slots to reduce friction and provide entirely esthetic brackets with no shown metal parts. Because of the recent development of the new ceramic brackets, the study of frictional resistance in ceramic brackets needs to be revisited. Therefore, this study aims to assess and compare the frictional resistance generated among various self-ligating ceramic brackets that are used these days.

Materials and methods

Brackets and archwires

Four groups of passive self-ligating brackets from different manufacturers, including Damon Q2 (stainless steel), Damon Clear2 (polycrystalline alumina), Truklear (polycrystalline alumina), and Clarity Ultra (micro-crystalline alumina), were used in the experiment (Table1). All brackets have 0.022x 0.028 -in declared slot size with no slot modification. Five bracket positions (central incisor, lateral incisor, canine, first premolar, and second premolar from the upper right quadrant) were used in a test in each group. Half of full-length 0.019 × 0.025 -in stainless steel archwires (OrthoFormII square; Permachrome Resilient, 3M) were used. Before the assessment, all brackets and archwires were cleaned and dried with 95% ethanol and compressed air, respectively.

Model preparation

Four replicas of the laser-based 3D printing (stereolithography; SLA) resin acrylic maxillary models were prepared for each experimental group. The model was fabricated from a real patient model who has finished orthodontic treatment with every tooth aligned in its ideal positions according to an OrthoFormII square arch form (3M). Half of full length 0.019 × 0.025 -in stainless steel archwire (OrthoFormII square; Permachrome Resilient, 3M) was used as a reference to align the bracket position to achieve the passive movement of the archwire and prevent the unwanted force that could occur from bracket-archwire deflection.[14,15] Each bracket was bonded to the model with Transbond XT (3M Unitek, Monrovia, CA, USA). After bonding, the section of 0.019 × 0.025 -in stainless steel archwire was removed.

Sample size

The sample size was calculated by conducting an a priori power analysis via the G Power software version 3.1(http://www.gpower.hhu.de/) with a given $\alpha = 0.05$, Power $(1-\beta) = 0.80$. The effect size was calculated by the data from the pilot study (Effect size = 0.955). Five samples in each group were needed.

Frictional analysis in sliding mechanics using a universal testing machine

The experimental setup was adapted from the previous studies.[16] Only half-arch brackets with half-length archwire were used. The measurement was performed on the right quadrant of the maxillary model.

The model with bonded brackets was mounted to a custom-made metal plate base that was secured to a universal testing machine (EZ-S, Shimadzu, JAPAN). The brackets were engaged to the wire by a self-ligation mechanism as a manufacturer's recommendation. The distal end of the archwire was gripped to a 50N tension-loading cell of a universal testing machine (Figure 1A).

A 0.019 × 0.025 -in stainless steel archwire was drawn through the brackets at a speed of 0.5 mm/min for 10 minutes at room temperature in a dry state. Each combination was repeated five times. New archwire and brackets were used in each experiment to prevent the influence of wear from the archwire and bracket. Frictional force data were collected from the universal testing machine. Static friction was set at the first peak at the beginning of the movement. The kinetic friction was then calculated as the mean of the frictional force measured during 5 mm of displacement (Figure 1B).

Statistical analysis

The frictional force's mean and standard deviation were calculated for each combination of the bracket and archwire. Shapiro-Wilk was used for the normality test. Analysis of variance (ANOVA) was used to compare the effect of bracket types on friction. Pairwise comparisons of the significant differences were performed using the Bonferroni post-hoc test. The *p*-value< 0.05 was considered statistically significant. The statistical comparisons were performed using SPSS software version 25.0. (SPSS, Inc., Armonk, NY, USA).

Bracket	Material	Design	Manufacturer
Damon Q2	Stainless steel	Passive self-ligating	Ormco (Orange, CA)
Damon Clear2	Polycrystalline alumina	Passive self-ligating	Ormco (Orange, CA)
Truklear	Polycrystalline alumina	Passive self-ligating	Forestadent (Pforzheim ,Germany)
Clarity Ultra	Micro-crystalline alumina	Passive self-ligating	3M Unitek (Monrovia, CA)

Table 1. List of evaluated Self-Ligating Brackets.

	Damon Q2 (torque/angulation)	Damon Clear2 (torque/angulation)	Truklear (torque/angulation)	Clarity Ultra (torque/angulation)
Central	+15 / 5°	+15 / 5°	+17 / 4°	+17 / 4°
Lateral	+8/ 9°	+6 / 9°	+10 / 8°	+10 / 8°
Cuspid	+7 / 5°	+7 / 5°	-7 / 8°	0 / 8°
Bicuspid	-11 / 2°	-11 / 2°	-7 / 0°	-7 / 0°

Table 2. Torque and angulation of brackets.

Brackets	n	Static mean	SD	F	*p*-value
Damon Q2	5	14.401	6.399	9.216	0.002*
Damon Clear2	5	17.991	6.235		
Truklear	5	20.292	4.378		
Clarity Ultra	5	35.902	5.338		
	Damon Q2	Damon Clear2	Truklear	Clarity Ultra	
Damon Q2	-	1.000	1.000	0.001*	
Damon Clear2	1.000	-	1.000	0.011*	
Truklear	1.000	1.000	-	0.042*	
Clarity Ultra	0.001*	0.011*	0.042*	-	

Table 3. Descriptive statistics and statistical comparisons (One-way ANOVA) of static friction (g). Bonferroni post-hoc analysis; SD, standard deviation; $*p < 0.05$

Results

The MBT prescription or the equivalent value of brackets was selected for the study. Torque and angulation values according to manufacturers are shown in Table 2.

Static and kinetic friction and the comparison of resistance force among the bracket groups are shown in Tables 3, Table 4, and Figure 2. The mean static friction of Damon Q2, Damon Clear 2, Truklear, and Clarity Ultra were 14.401, 17.991, 20.292, and 35.902 g, respectively. The mean kinetic friction of Damon Q2, Damon Clear 2, Truklear, and Clarity Ultra were 66.049, 38.680, 82.898, and 138.561 g, respectively. Shapiro-Wilk test showed the normal distribution of the data of static friction and kinetic friction (*p*=0.142 and *p*=0.818, respectively).

One-way ANOVA showed that there were significant differences in static and kinetic friction among the bracket groups (*p*<0.05). Post-hoc pairwise comparisons (Bonferroni test) in static friction showed a significant difference between Clarity Ultra and three groups of self-ligating brackets, but no significant differences were shown among the three groups. For kinetic friction, the Bonferroni post hoc test also showed a significant difference between Clarity Ultra and three groups of self-ligating brackets. No significant differences were shown between Damon clear2 versus Damon Q2 and DamonQ2 versus Truklear (*p*<0.05).

Brackets	n	Kinetic mean	SD	F	*p*-value
Damon Q2	5	66.049	6.516	18.950	<0.001*
Damon Clear2	5	38.680	23.467		
Truklear	5	82.898	21.661		
Clarity Ultra	5	138.561	22.439		
	Damon Q2	Damon Clear 2	Truklear	Clarity Ultra	
Damon Q2	-	0.209	1.000	<0.001*	
Damon Clear2	0.209	-	0.042*	<0.001*	
Truklear	1.000	0.042*	-	0.014*	
Clarity Ultra	<0.001*	<0.001*	0.014*	-	

Table 4. Descriptive statistics and statistical comparisons (One-way ANOVA) of kinetic friction (g). Bonferroni post-hoc analysis; SD, standard deviation; $*p < 0.05$

Discussion

Previous studies evaluated the frictional resistance by pulling the straight segment of the archwire through the straight-aligned brackets with compensation of built-in tip and torque. At 0° angulation, the passive self-ligating brackets showed nearly zero resistance force.[3,17,18] However, there was a controversy about this kind of experimental setup that can not represent what happens in clinical practice.[4] As a tooth moves along the archwire, it moves in tipping and uprighting sequences and is experienced in binding.

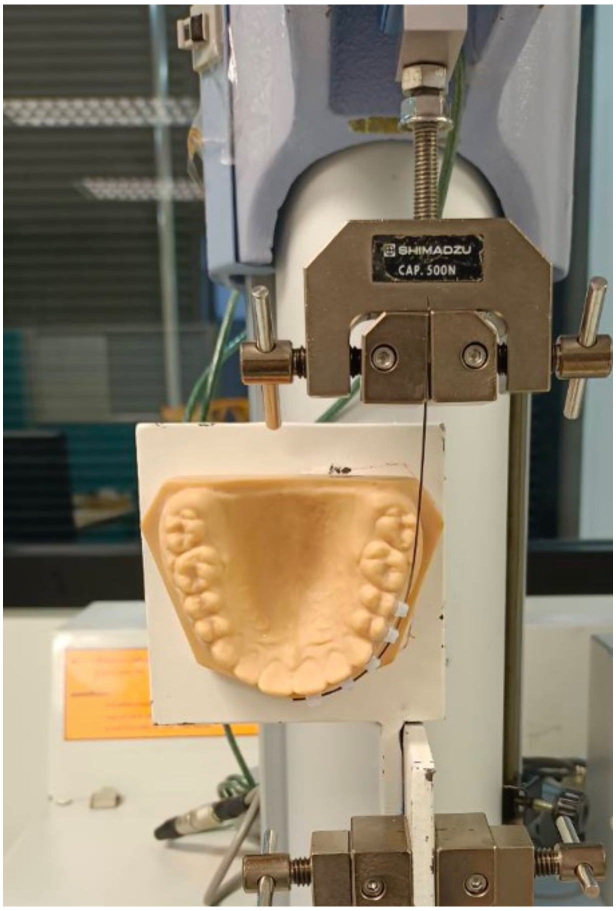

Figure 1 (A). Experimental setting.

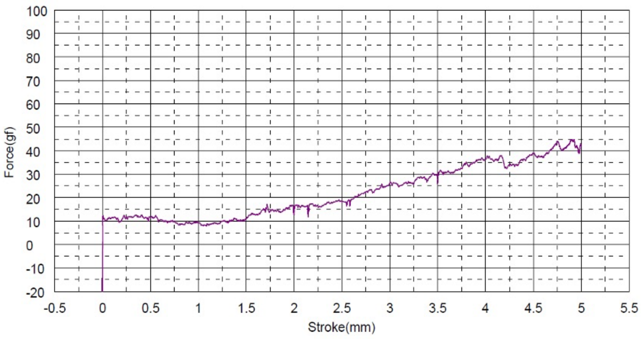

Figure 1 (B). Force-displacement graphs.

Several studies used a modification from the study by Tidy.[19] The canine bracket was pulled along the leveled full-arch resin model by a coil spring at a certain distance.[20,21] The force system acting on this bracket was recorded and calculated. However, the shown force-displacement graph revealed several pronounced peaks as a result of cycles of tipping and uprighting movement of the bracket. These fluctuations of value explain the large variations that can complicate the calculation of the mean and result in the uncertain reliability of the data.

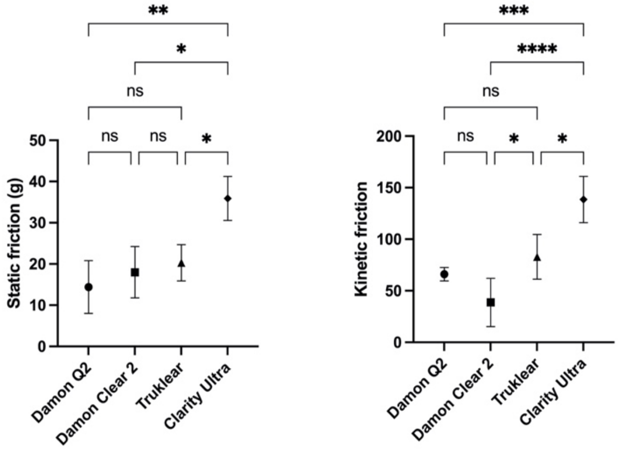

Figure 2. Mean with the standard deviation and pairwise comparisons of static and kinetic frictional force.

Other studies showed that when it comes to binding, types of materials and modes of ligation have minimal effects on the resistance. There was no significant difference in all types of brackets when the contact angle increased to certain angulations.[22,23] Therefore, to compare the frictional resistance generated among the various types of materials, the effect of binding was minimized in our study.

Our experimental setup was adapted from the study of Kim and Beak.[16] Brackets were positioned passively to the archwire, and only half-length of the archwires were used.

Static friction in our study was collected at the beginning of the movement, where the wire and bracket slots were arranged in the passive configuration. Because the clearance existed and the passive self-ligating brackets provided no ligation force, the resistance in this static frictional test is then equal to friction, which comes from the coefficient of friction determined solely by the materials.[23] No significant difference was found among the three groups of self-ligating ceramic and stainless steel brackets except Clarity Ultra in the static frictional test.

Kinetic friction in our study showed a significantly higher value than static friction. This could be explained by the increase of the contact angle (θ) when the curve of the archwire moved through the bracket slot while the displacement continued. In this situation, the resistance came from the combination of friction and binding, as in clinical practice, where the passive stage no longer exists.

Clarity Ultra also showed the significantly highest kinetic friction among the tested groups. Other groups of self-ligating ceramic brackets showed no significant differences from self-ligating stainless steel brackets.

Literature showed that the same type of self-ligating brackets (active or passive) exhibited a comparable frictional resistance force between stainless steel and ceramic brackets. Wu C-L et al.[22] found no significant difference between passive self-ligating stainless steel (Damon3MX) and passive self-ligating ceramic brackets(GeniusCrystal, Damon Clear2) when coupling with 0.016x0.022-in NiTi wire. Lee and Hwang[24] found no significant differences between active self-ligating stainless steel brackets (Quick) and active self-ligating ceramic brackets (Clippy-C) when coupling with 0.019x0.025-in stainless steel wire.

However, a recent study by Bazergan et al.[25] showed that Clarity Ultra had the significantly highest frictional resistance force among various self-ligating ceramic brackets (Clarity Ultra, Damon Clear2, Empower Clear2) when coupling with 0.019x0.025-in stainless steel wire, whereas Damon Clear2 and Empower Clear2 had a comparable resistance force. The authors stated that the high resistance force from Clarity Ultra brackets could be associated with its micro-morphology – bracket design, clip shape, slot size and tolerance, and materials characteristics.

Our findings were consistent with the studies mentioned above that micro-crystalline self-ligating ceramic brackets (Clarity Ultra) showed significantly higher frictional resistance, and certain types of self-ligating ceramic brackets have a comparable resistance force to self-ligating stainless steel brackets.

Factors such as torque and angulation value, the actual slot dimensions, and the bracket design may affect the resistance force in this study, especially in the kinetic frictional test, where these factors could affect the amount of binding.

Slot clearance has been found to be inversely proportional to the resistance force.[26] Several studies found errors in dimensional accuracy as indicated by manufacturers of self-ligating brackets. Earlier studies reported that the mean slot dimension of Damon brackets usually showed oversized.[23,27] Slot design also affects the different resistance forces. The rounded inner slot reduces binding and notching, resulting in less resistance.[28] On the other hand, increasing bracket width will decrease the critical contact angle, resulting in a more binding tendency.[23]

According to the manufacturer, Clarity Ultra (micro-crystalline alumina) brackets were made from fine-grained aluminum oxide to improve the strength property. However, no evidence was reported that decreased grain size could influence frictional force.

Surface roughness could be another factor affecting frictional behavior.[29] However, The material with rougher surfaces does not always exhibit more friction than the smoother one because several factors likely contribute to friction.[6,30,31]

The limitations of this study involved the prescription that was slightly different in each group. The actual slot dimension was unable to be restricted in this study. Due to the inconsistency of experimental methods, the results from various studies are difficult to compare. Clinicians should consider the results with caution. Moreover, this *in-vitro* study could not simulate the clinical conditions in which many factors, such as mastication forces, temperature, and saliva, can affect the results.

Further studies should include a study of surface analysis and findings of the critical contact angle in second-order angulation and first-order angulation of these investigated brackets for a better understanding of this topic.

Conclusions

This in-vitro study of frictional resistance showed that Clarity Ultra, made from micro-crystalline alumina, generated the highest frictional resistance among the tested groups in the static frictional test, which was performed in the passive configuration and in the kinetic frictional test where some degrees of binding were involved.

Other groups of self-ligating ceramic brackets (Damon Clear2, Truklear: polycrystalline alumina) generated a comparable frictional force to self-ligating stainless steel brackets (Damon Q2).

Acknowledgements

This work was supported by Walailak University Fund. The authors declare no conflict of interest.

Declaration of Interest

The authors report no conflict of interest.

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