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AIRFLOW POLISHING REDUCES CLIP-OPENING RESISTANCE IN INTRAORALLY EXPOSED PASSIVE SELF-LIGATING BRACKETS

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Abstract

Background: Passive self-ligating brackets promise reduced friction but second clip deformation risks from intraoral debris after prolonged exposure, potentially complicating clinical use. **Methods:** In this split-mouth study, Damon Ultima brackets (Ormco) were bonded to palatal surfaces of maxillary first premolars in 17 healthy orthodontic patients (mean age 18.4 ± 2.9 years). After 12 weeks intraoral exposure, brackets were debonded; one per patient received glycine-based airflow polishing (3M Clinpro Glycine), the other served as untreated control. Clips were tested closed on a custom apparatus with tensile force (5 mm/min, 3 repeats/bracket; n=34 brackets, 102 measurements) for minimum opening resistance, compared to baseline (T_0). **Results:** Post-exposure, controls showed significantly higher initial clip-opening force vs. T_0 ($p<0.05$). Airflow normalized initial forces to T_0 levels, with significantly lower resistance vs. controls ($p<0.05$); repeated openings averaged higher but showed no group difference. Conclusions: Airflow polishing mitigates intraoral debris-induced clip resistance increases, easing clinical manipulation. **Aim:** To evaluate airflow polishing's effect on clip-opening resistance in passive self-ligating brackets post-12-week intraoral exposure.

Keywords: Self-Ligating Brackets, Clip-Opening Resistance, Airflow Polishing, Intraoral Exposure, Damon Ultima.

INTRODUCTION

Fixed orthodontic appliances remain a cornerstone for correcting malocclusions, with archwires traditionally secured via metal or elastomeric ligatures. Self-ligating brackets, introduced in the 1930s and refined since the 1990s, integrate a clip mechanism to secure the archwire without external ligatures. Systems like the recent Damon Ultima (2022) feature advanced rhomboid slot geometry for enhanced torque control. Proponents highlighted friction-potentially up to 60% force loss in conventional systems [1,2], enabling physiological forces, alveolar remodeling, arch expansion, fewer extractions, shorter treatment times, extended visit intervals, faster ligation, improved comfort, and lower plaque [3-8]. Passive clips minimize friction during sliding, active clips enhance torque/rotation, and interactive (hybrid) designs adapt across phases.

Yet, clinical evidence is mixed. Meta-analyses question superiority in treatment duration, arch expansion, or hygiene [9, 10, 11-17]. Clip fragility leads to deformation, breakage,

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or detachment, especially under occlusal forces or improper handling, with higher costs and complex learning curves . Intraoral exposure exacerbates issues: saliva's electrolytes, proteins, and microbes promote biofilm, corrosion, and debris at bracket wire interfaces, increasing roughness and friction [18-26]. Corrosion types-uniform, pitting, crevice, galvanic, intergranular, fretting, stress, and microbiological release ions, degrade passivity, and impair function, particularly in acidic/fluoride environments [27-29].

Ligation alternatives vary metal ligatures offer durability but are time-intensive; elastomeric ones degrade rapidly (50% force loss in 24 hours), trap plaque, and raise friction [30-33]. Self-ligating systems save ligation time (e.g., 57 seconds vs. 11 minutes for metal) but risk clip failure from calculus or remnants.

Air powder polishing (APP), introduced in 1977, counters debris using air-water-powder jets (sodium bicarbonate, glycine, erythritol) [34-37]. It outperforms rubber-cup methods in speed, effort, heat avoidance, and bracket/wire safety, reducing interface friction (e.g., 4.52 N to 1.27 N). Glycine/erythritol minimizes abrasion vs. bicarbonate, preserving enamel and surfaces [38-47]. APP enhances efficiency (5-10 seconds/bracket) and comfort, with high satisfaction [45, 48, 49].

Despite these benefits, studies on clip mechanisms post-exposure are scarce, especially integrating APP's debris removal with functional testing like clip-opening resistance.

The aim of this study is to compare the clip-opening resistance of Damon Ultima brackets after 12 weeks of intraoral exposure and subsequent debris accumulation, between brackets treated with airflow and those in an untreated control group.

MATERIALS AND METHODS

Materials

This non-pharmacological clinical study was conducted on 17 patients (aged 12–33 years) undergoing fixed orthodontic treatment at the Department of Orthodontics, Faculty of Dentistry, Istanbul Okan University. All participants were systemically healthy and active fixed appliance therapy. Ethical approval was obtained from the Istanbul Okan University Ethics Committee (Approval No: 186, Date: 12.02.2025).

The passive self-ligating brackets evaluated were Damon Ultima maxillary first premolar brackets (Ormco Orthodontics, USA), manufactured according to the MBT prescription with a 0.022-inch slot. These brackets were made of PH 17-4 stainless steel alloy (grade 630, 1.4542), containing approximately 17% chromium and 4% nickel. In all patients, conventional MBT brackets (Mini Master, American Orthodontics) with a 0.022 × 0.025-inch slot were used as part of routine treatment, while one Damon Ultima bracket was bonded on the palatal surface of each maxillary first premolar (teeth #14 and #24) and used as an orthodontic button. The airflow powder used for professional cleaning in the experimental group was a glycine-based product (3M ESPE Clinpro Glycine Prophy Powder, Minnesota, USA), which is indicated for safe biofilm removal around orthodontic appliances. In the control group, no airflow application was performed. To quantify the

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force required to open the bracket clips, a custom-designed experimental setup incorporating a digital force gauge (Lyman, Virginia, USA) was used. The system included a NEMA 17 stepper motor (NEMA, Virginia, USA) providing controlled linear motion. The stepper motor had a step angle of 1.8° (200 steps per revolution), was driven at 12 V with a current of 1.4 A, and produced a torque of 3.2 kg/cm. This configuration allowed precise and reproducible application of tensile force to open the clip mechanism. The bonding protocol for the in vivo phase involved two different adhesives, depending on the stage of the study. For the initial bonding described in Section 3.2, Assure Plus Bond (Reliance, Illinois, USA) and GC Ortho Connect adhesive (GC Orthodontics, Breckerfeld, Germany) were used following the manufacturers' instructions. For the main experimental bonding procedure (Section 3.2.3), BracePaste adhesive (American Orthodontics, Wisconsin, USA) was used.

Methods

In all patients, conventional MBT brackets (Mini Master, American Orthodontics) with a 0.022 × 0.025-inch slot were placed as part of their comprehensive orthodontic treatment. In those who consented to participate, one Damon Ultima passive self-ligating bracket (Ormco Orthodontics, USA) was bonded to the palatal surface of each maxillary first premolar (teeth #14 and #24) and used as an orthodontic button. Bonding was performed according to manufacturers' recommendations. Initially, the palatal enamel surfaces were etched with 37% orthophosphoric acid for 30 seconds, rinsed, and lightly air-dried. Assure Plus Bond (Reliance, Illinois, USA) was applied, air-thinned for 5 seconds, and light-cured for 3 seconds using a VALO LED curing unit (Ultradent, Utah, USA). GC Ortho Connect adhesive (GC Orthodontics, Breckerfeld, Germany) was applied to the bracket bases, excess composite was carefully removed particularly around the clip area and the brackets were light-cured for 6 seconds per exposure at 1400 mW/cm² with the VALO unit.

Airflow Application

After 12 weeks of intraoral exposure, airflow application was performed extraorally on the Damon Ultima brackets bonded to tooth #14 in each patient, forming the experimental group. The control brackets (tooth #24) received no airflow treatment. Glycine-based airflow powder (3M ESPE Clinpro Glycine Prophy Powder, Minnesota, USA) was applied following parameters reported in the literature. The nozzle was positioned at a 60°-80° angle relative to the bracket surface, at a distance of 3–5 mm. Application time was approximately 5 seconds per bracket, within a range considered safe for enamel and soft tissues. Air pressure was set to 60-80 psi (4-4.5 bar), which is regarded as optimal for glycine powders. During application, the nozzle was moved in a circular (clockwise) pattern over the bracket to ensure uniform cleaning, avoiding prolonged exposure at a single point.

Experimental Setup and Force Measurement

The experimental system consisted of two black acrylic blocks moving along a single linear axis, a NEMA 17 stepper motor, a control unit, and a digital force gauge. One block

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was fixed and carried a custom mechanism designed to open the Damon Ultima clip, while the other block was movable and equipped with the digital force gauge to record forces.

The NEMA 17 stepper motor (step angle 1.8°, 200 steps/revolution, 12 V, 1.4 A, 3.2 kg·cm torque) generated constant linear pulling motion at 5 mm/min, by converting its rotational movement into horizontal displacement via a linear carriage. Motor parameters, including speed and direction, were controlled using Arduino IDE software (Arduino Uno Board, Italy), allowing precise control over motion.

The bracket holder was custom-designed and CNC-milled from metal to match the base morphology of Damon Ultima 0.022-inch MBT maxillary premolar brackets, ensuring accurate and stable positioning during testing. The opening mechanism consisted of a vertically oriented probe-like arm that engaged the clip region and applied an initial force of approximately 150 grams. On the experimental platform, the clip-opening movement occurred along a sliding axis parallel to the bracket surface.

In the test protocol, the 90° angled arm of the force gauge initiated horizontal loading via the vertically positioned probe that fit precisely into the bracket slot. As the stepper motor advanced at 5 mm/min, tensile force increased gradually until the clip mechanism started to move. The force value recorded at the instant of initial clip movement was defined as the maximum resistance force required to open the bracket clip. All measurements were performed under dry conditions at room temperature to standardize the testing environment.

Bonding Procedure

For the main experimental phase, the palatal surfaces of the maxillary premolars were etched with 37% orthophosphoric acid for 30 seconds, rinsed for 15 seconds, and air-dried for 10 seconds. BracePaste adhesive (American Orthodontics, Wisconsin, USA) was applied to the bracket bases. Excess composite was removed with a dental explorer, taking care not to interfere with the clip mechanism. Damon Ultima brackets were bonded to teeth #14 and #24 in the same session and light-cured for 6 seconds each using a VALO Cordless curing unit (Ultradent, Utah, USA).

Debonding Procedure

After 12 weeks of intraoral service, the Damon Ultima brackets were carefully removed using a lingual bracket-removing plier, ensuring that the clip mechanisms remained unopened. Residual adhesive on the tooth surfaces was then removed with tungsten carbide burs, and the enamel was polished with rubber polishers to restore a smooth surface.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics version 27. The normality of data distribution was assessed with Kolmogorov–Smirnov and Shapiro–Wilk tests, and all variables showed normal distribution. Descriptive statistics (minimum, maximum, mean, and standard deviation) were calculated. For comparison of quantitative variables

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between the airflow-treated and control groups, the Student's t-test was used. A p value < 0.05 was considered statistically significant.

RESULTS

The study was conducted on a total of 17 individuals (9 males and 8 females) aged between 12 and 27 years. The mean age was 18.4 ± 2.9 years.

The clip-opening resistance values in the experimental group at the first measurement ranged from 280 to 900 g, with a mean value of 560.47 ± 160.8 g. For the T0 group, the clip-opening resistance values at the first measurement ranged from 244 to 778 g, with a mean value of 450.53 ± 167.52 g. There was no statistically significant difference between the experimental group and the T0 group in terms of mean clip-opening resistance values at the first measurement (p > 0.05).

Table 1: Comparison of Measurements

Measurement	Min	Max	Mean ± SD
Experimental	280	900	560.47 ± 160.8
T0	244	778	450.53 ± 167.52
p-value			**0.068**

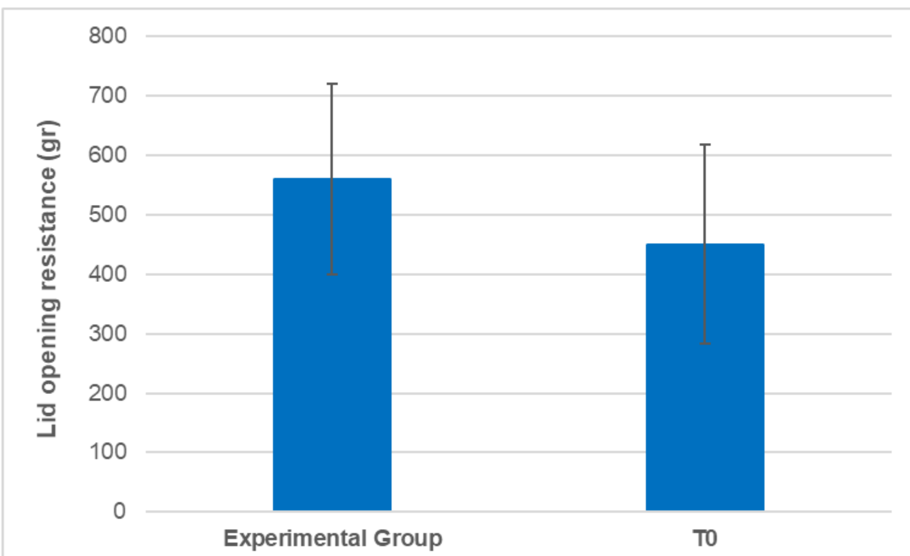

Figure 1: Comparison of First Measurement Results Between the Experimental Group and T0

Control vs T0:

The clip-opening resistance values in the control group at the first measurement ranged from 408 to 1200 g, with a mean value of 759.65 ± 214.93 g. For the T0 group, the clip-opening resistance values ranged from 244 to 778 g, with a mean value of 450.53 ± 167.52 g. The mean clip-opening resistance in the control group was statistically significantly higher than that of the T0 group (p = 0.001; p < 0.05).

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Table 2: Comparison of First Measurement Results Between the Control Group and T0

Measurement	Min	Max	Mean ± SD
Control	408	1200	759.65 ± 214.93
T0	244	778	450.53 ± 167.52
p-value			**0.001***

(Student's t-test, p < 0.05)

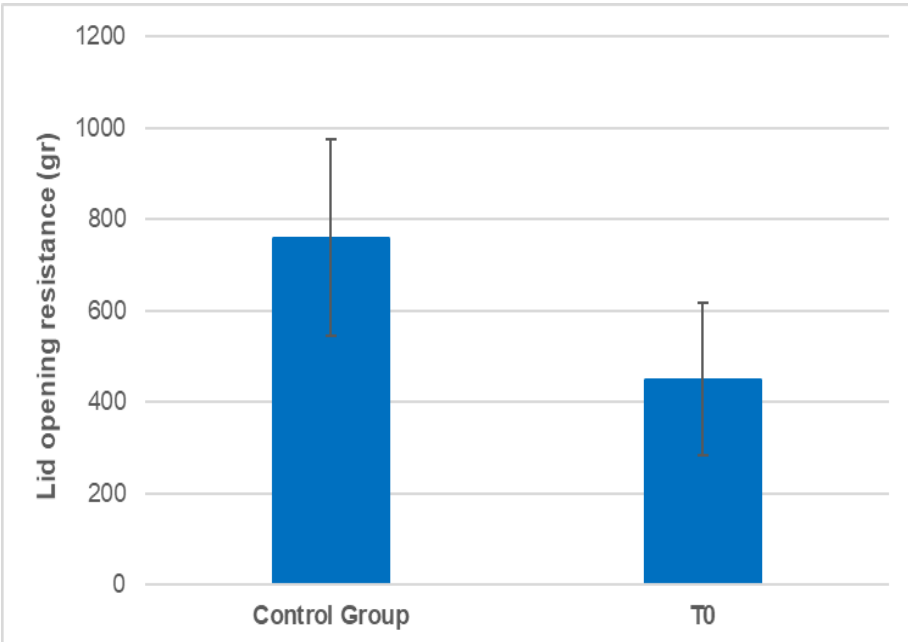

Figure 2: Comparison of First Measurement Results Between the Control Group and T0

Mean Values Comparison

The mean clip-opening resistance values in the experimental group ranged from 380.67 to 666.67 g, with a mean of 512.29 ± 92.65 g. For the T0 group, the mean clip-opening resistance values ranged from 312.33 to 575.33 g, with a mean of 440.09 ± 79.86 g. The mean clip-opening resistance in the experimental group was statistically significantly higher than that of the T0 group ($p = 0.026$; $p < 0.05$).

Table 3: Comparison of Mean Measurement Values Between Experimental and T0 Groups

Group	Min	Max	Mean ± SD
Experimental	380.67	666.67	512.29 ± 92.65
T0	312.33	575.33	440.09 ± 79.86
p-value			**0.026***

(Student's t-test, p < 0.05)

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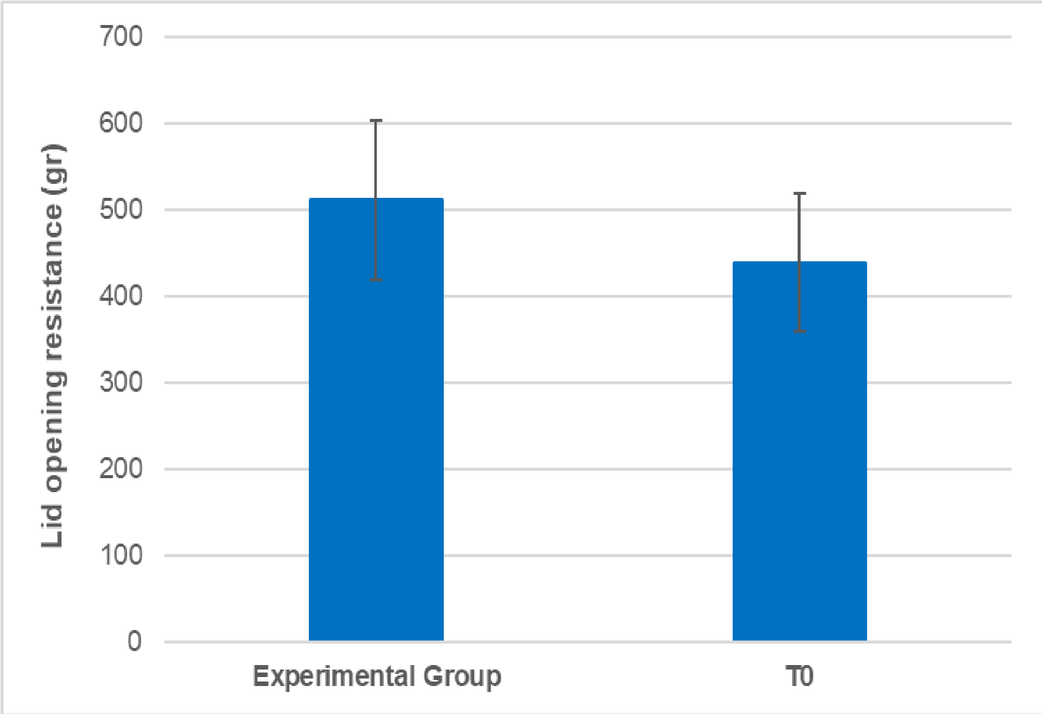

Figure 3: Comparison of Mean Measurement Values Between the Experimental Group and T0

Control vs T0 – Mean Values

The mean clip-opening resistance values in the control group ranged from 343.33 to 811.33 g, with a mean of 571.37 ± 135.86 g. For the T0 group, the mean values ranged from 312.33 to 575.33 g, with a mean of 440.09 ± 79.86 g.

The mean clip-opening resistance in the control group was statistically significantly higher than that of the T0 group ($p = 0.002$; $p < 0.05$).

Table 4: Comparison of Mean Measurement Values Between the Control Group and T0

Group	Min	Max	Mean ± SD
Control	343.33	811.33	571.37 ± 135.86
T0	312.33	575.33	440.09 ± 79.86
p-value			**0.002***

(Student's t-test, $p < 0.05$)

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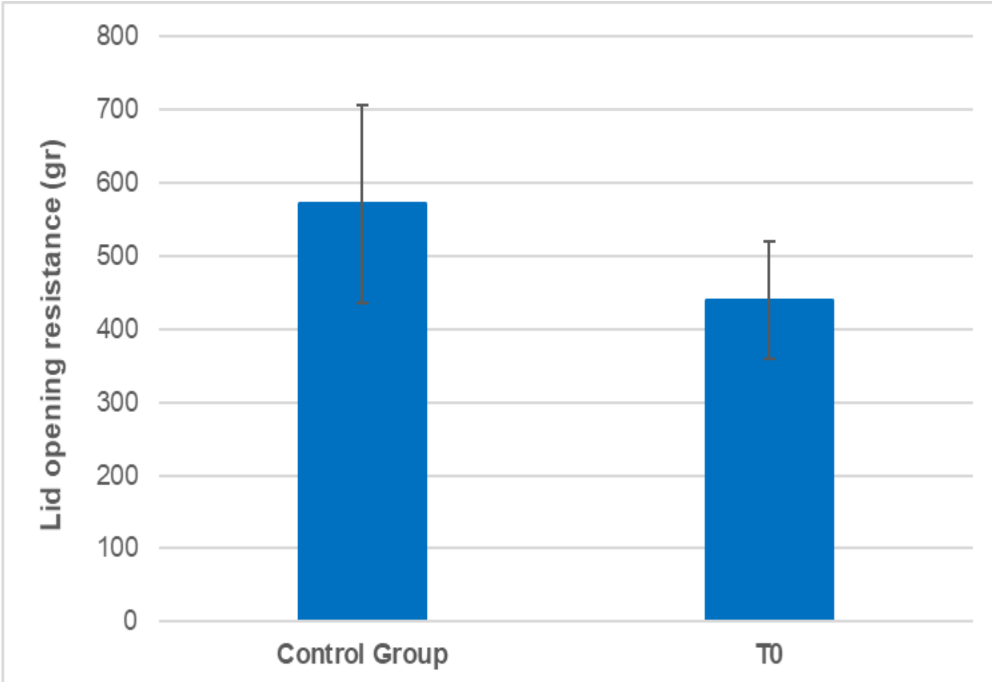

Figure 4: Comparison of Mean Measurement Values Between the Control Group and T0

Results Statement (Experimental vs Control)

The clip-opening resistance values in the control group were statistically significantly higher than those in the experimental group ($p = 0.004$; $p < 0.05$).

The clip-opening resistance values in the experimental group at the first measurement ranged from 280 to 900 g, with a mean of 560.47 ± 160.8 g. In the control group, the values ranged from 408 to 1200 g, with a mean of 759.65 ± 214.93 g.

The mean clip-opening resistance in the control group was statistically significantly higher than that of the experimental group ($p = 0.004$; $p < 0.05$).

Table 5: Comparison of First Measurement Results Between the Experimental and Control Groups

Group	Min	Max	Mean ± SD
Experimental	280	900	560.47 ± 160.8
Control	408	1200	759.65 ± 214.93
p-value			**0.004***

(Student’s t-test, $p < 0.05$)

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
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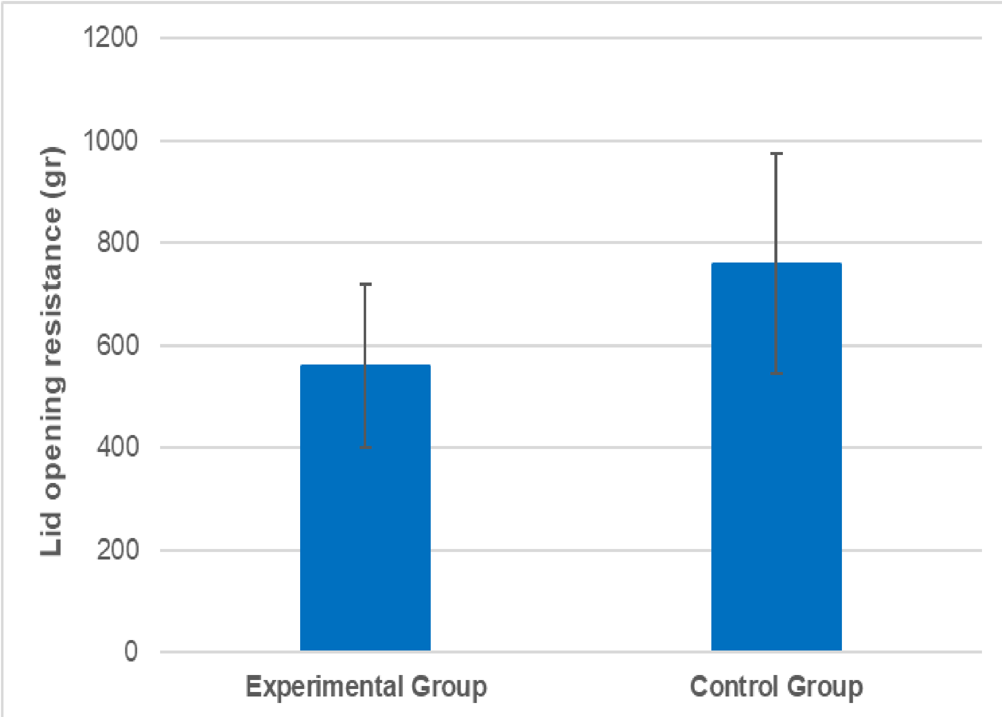

Figure 5: Comparison of First Measurement Results Between the Experimental and Control Groups

Mean Values – Experimental vs Control

There was no statistically significant difference between the experimental and control groups in terms of mean clip-opening resistance values ($p = 0.150$; $p > 0.05$).

The mean clip-opening resistance values in the experimental group ranged from 380.67 to 666.67 g, with a mean of 512.29 ± 92.65 g. In the control group, the mean values ranged from 343.33 to 811.33 g, with a mean of 571.37 ± 135.86 g.

There was no statistically significant difference between the experimental and control groups in terms of mean clip-opening resistance values ($p > 0.05$).

Table 6: Comparison of Mean Measurement Values Between the Experimental and Control Groups

Group	Min	Max	Mean ± SD
Experimental	380.67	666.67	512.29 ± 92.65
Control	343.33	811.33	571.37 ± 135.86
p-value			**0.150**

(Student’s t-test)

Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/
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ISSN (Online):0493-2137
E-Publication: Online Open Access
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DOI: 10.5281/zenodo.20438595

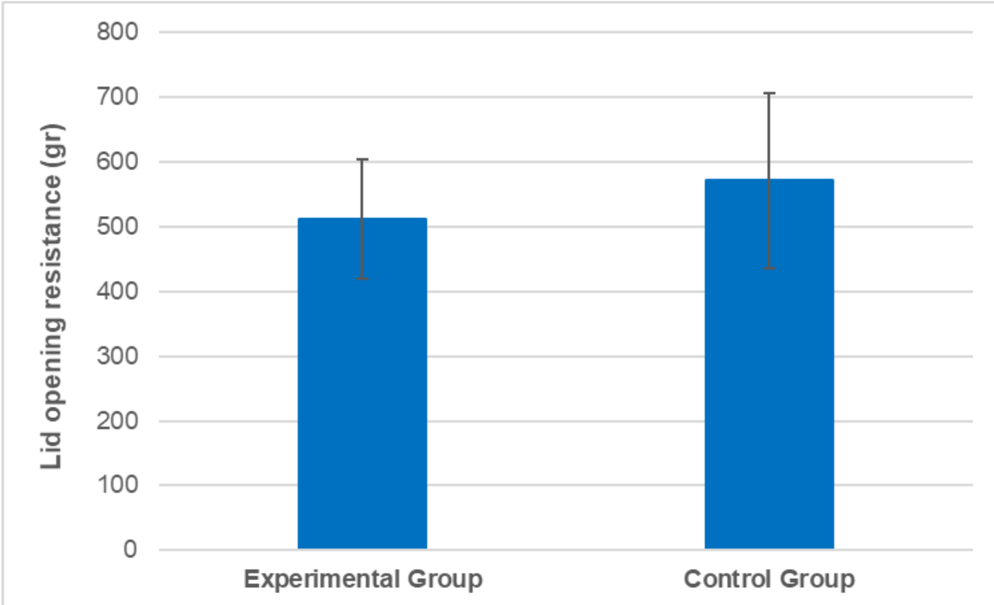

Figure 6: Comparison of Mean Measurement Values Between the Experimental and Control Groups

4.1 Evaluation of Method Reliability

To assess the reliability of the measurement method, the protocol described by Dinesh et al. [46] was used as a reference.

Accordingly, four-link segments were cut from Ormco Closed Elastic Chains (Ormco, California, USA) and placed into the experimental setup. These passive segments, initially measuring 10 mm in length, were stretched at a constant rate until reaching 20 mm. The tensile forces generated at each 1 mm increment were recorded.

The measurements obtained using the Lyman Digital Force Gauge in the clinical setup were then compared with those obtained using an M500-30CT Universal Testing Machine (Material Testing Laboratory, Faculty of Engineering and Natural Sciences, Istanbul Okan University). The data obtained from the two independent measurement systems were statistically analyzed to evaluate the reliability and consistency of the experimental method.

Table 7: Comparison table of universal testing device and experimental setup measurements

Displacement	Device	n	Mean ± SD	p-value
1 mm	Digital Force Gauge	10	75.0 ± 5.52	0.740
	Universal Testing Machine	10	76.2 ± 9.82	
2 mm	Digital Force Gauge	10	112.7 ± 7.83	0.977
	Universal Testing Machine	10	112.6 ± 7.24	
3 mm	Digital Force Gauge	10	149.4 ± 8.5	0.877
	Universal Testing Machine	10	150.0 ± 8.6	
4 mm	Digital Force Gauge	10	171.2 ± 4.73	0.903

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	Universal Testing Machine	10	171.5 ± 6.06	
5 mm	Digital Force Gauge	10	198.3 ± 10.29	0.162
	Universal Testing Machine	10	204.3 ± 7.94	
6 mm	Digital Force Gauge	10	229.6 ± 6.72	0.668
	Universal Testing Machine	10	227.8 ± 11.17	
7 mm	Digital Force Gauge	10	263.4 ± 9.52	0.695
	Universal Testing Machine	10	261.2 ± 14.64	
8 mm	Digital Force Gauge	10	290.1 ± 14.7	0.063
	Universal Testing Machine	10	276.8 ± 15.32	
9 mm	Digital Force Gauge	10	327.6 ± 9.03	0.171
	Universal Testing Machine	10	315.0 ± 25.68	
10 mm	Digital Force Gauge	10	366.1 ± 10.4	0.202
	Universal Testing Machine	10	351.8 ± 32.5	

Results Statement (Method Reliability)

No statistically significant differences were found between the measurements obtained using the digital force gauge and the universal testing machine at any displacement level ($p > 0.05$).

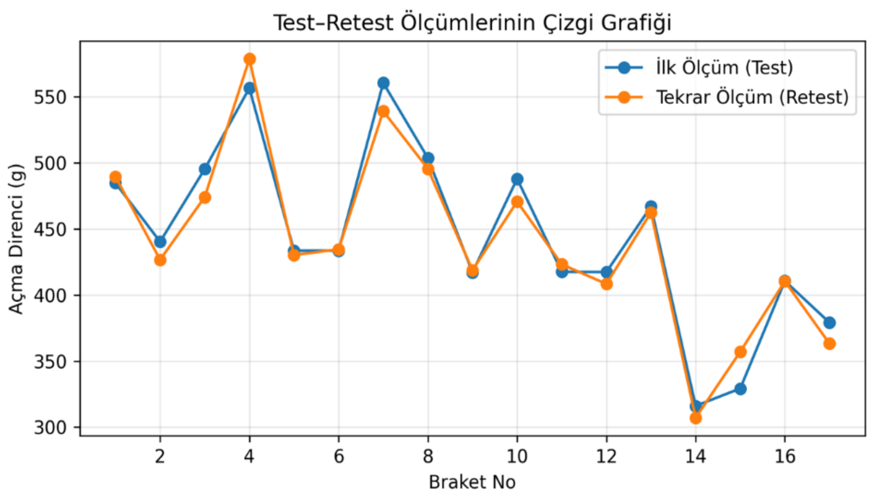

Figure 7: Test-retest graph

Reliability

The results of the test–retest reliability analysis conducted on 17 Damon Ultima passive self-ligating brackets for clip-opening resistance are presented. To evaluate short-term repeatability, the clip-opening resistance values were re-measured after a one-week interval.

Paired t-test analysis revealed no statistically significant difference between the initial and repeated measurements ($p > 0.05$). This finding confirms the high short-term reproducibility and reliability of the measurement method.

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Furthermore, graphical analysis demonstrated that the test and retest values were closely aligned, with data points distributed near the line of identity. This observation further supports the consistency and stability of the measurement protocol.

DISCUSSION

Debris and plaque accumulation on orthodontic brackets is inevitable during treatment, regardless of system, leading to aesthetic and mechanical issues such as increased surface roughness and friction at the bracket-archwire interface. This impairs sliding mechanics and tooth movement. Air powder polishing (APP) effectively removes such deposits, though sodium bicarbonate-based APP may elevate roughness and friction. Critically, debris removal's friction-lowering benefits outweigh potential cleaning-induced increases. Leite and Fagundes demonstrated over 300% higher friction in uncleaned vs. APP-treated brackets, underscoring cleaning's role. This study evaluated clip-opening resistance in self-ligating brackets post-debris accumulation and assessed APP's influence, advancing clinical efficiency insights.

Literature on clip resistance post-intraoral exposure is scarce. While APP's friction effects on materials are studied, none target clip-opening resistance. Digital force gauges, validated against universal testers, measured forces here, aligning with prior uses for friction and decay assessments. Testing at 5 mm/min reflects literature speeds (0.5-50 mm/min show minimal impact). Dry, room-temperature conditions standardized measurements, avoiding saliva's friction elevation. APP parameters (5 s, 5 mm distance, 60-80 psi) balanced efficacy and minimal damage. Only stainless-steel Damon Ultima brackets minimized variability; 12-week exposure simulated extended self-ligating intervals [50-52]. Cutting pliers with water-cooled polishing ensured non-destructive debonding.

Baseline clip-opening force for Damon Ultima maxillary premolar brackets was 440.09 ± 76.86 g, aligning with Gandini et al.'s range (143.7-556.7 g) across systems, validating the protocol. Post-12-week exposure, resistance rose significantly: control group's first opening hit 759.6 g (309.12 g increase vs. baseline), with subsequent openings averaging lower (571.3 g; mean of first three: 571.37 g, +131.28 g). This indicates debris-induced stiffening, with first openings clinically most relevant given self-ligating's longer intervals.

APP mitigated effects: first-opening resistance was 560.47 g (significantly lower than control's 759.65 g), nearing baseline ($p=0.068$). Mean of first three (512.29 g) showed no significant control difference, suggesting partial restoration. Literature varies: Wilmes noted ~2.5% friction rise in metallic wires post-APP, with mild roughness; Leite found 5-s APP reduced friction/debris, but 10 s increased roughness. Here, APP countered debris more than it induced roughness, though not fully reverting to baseline likely due to surface changes or incomplete cleaning.

Intraoral aging progressively elevates friction/roughness [50-52]. and clip fragility risks deformation. Carneiro found no permanent damage post-cycles despite force variations. Damon Ultima's design may resist better, but debris challenges persist. APP's partial

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efficacy highlights need for optimized protocols (e.g., gentler powders like glycine) [38-40, 47].

Limitations include single-bracket type, dry testing (vs. saliva), and short exposure relative to full treatments. Future studies should test diverse systems, wet conditions, longer exposures, and clinical outcomes like treatment efficiency. These findings affirm intraoral debris increases clip resistance in passive self-ligating brackets, with APP offering practical mitigation for smoother clinical handling.

CONCLUSIONS

Passive self-ligating brackets exposed intraorally for 12 weeks showed significantly increased clip-opening resistance in both control and airflow-treated groups. Untreated controls required higher force for initial openings post-exposure compared to baseline (T0). Airflow normalized initial resistance to T0 levels, though repeated openings averaged higher. Airflow-treated brackets had lower resistance than controls initially, but not significantly for repeated means. The custom digital force gauge setup proved reliable and reproducible for orthodontic force measurements.

RECOMMENDATIONS

Few studies examine self-ligating clip mechanics; larger trials are needed to mitigate clinical failures. Given 12-week exposure mirrors routine intervals, routine airflow integration may reduce clip failure risk. Future designs should measure rotational forces with clinical instruments (e.g., screwdrivers) for greater realism.

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