ORIGINAL RESEARCH

Correlating Frictional Forces Generated by Different Bracket Types during Sliding and Surface Topography Using Scanning Electron Microscopy and Optical Profilometer

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Abstract

Aim: The study aims to correlate the frictional forces (FF) of four different types of commercially available ceramic brackets to their surface topography.

Materials and methods: Two monocrystalline (MC) brackets (CLEAR™, Adanta, Germany; Inspire ICE™, Ormco, USA), one polycrystalline (PC) bracket (Symetri Clear™, Ormco, USA), one clear hybrid esthetic bracket (DISCREET™, Adanta, Germany), and a stainless-steel (SS) bracket (Victory™, 3M Unitek, USA) served as control. Both static friction (SF) and kinetic friction (KF) were recorded during sliding using an Instron universal machine in dry settings. The bracket slot surface topography was evaluated. A scanning electron microscope (SEM) and a profilometer machine were used for assessment before and after sliding.

Results: Frictional forces values during sliding were as follows in descending order; Inspire ICE™, CLEAR™, DISCREET™, Symetri Clear™, and, lastly, Victory™. Also, DISCREET™ scored the highest in surface roughness (Sa) values followed by Symetri Clear™. None of the correlations were statistically significant.

Conclusion: Frictional forces produced during sliding were not always directly related to surface roughness. Monocrystalline ceramic brackets appeared to have the greatest FF and a low surface roughness. Furthermore, DISCREET™ scored a very low frictional value comparable to metal brackets yet showed the highest surface roughness. Metal brackets exhibited the greatest surface smoothness before sliding and the least SF.

Clinical significance: Predicting the FFs produced during sliding mechanics would help the practitioner while choosing the bracket system to be used, and while planning the treatment mechanics, how much force to deliver, and how much tooth movement to expect.

Keywords: Brackets, Ceramic, Kinetic friction, Monocrystalline, Orthodontics, Polycrystalline, Static friction, Surface roughness.

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Introduction

Frictional resistance can be observed between the archwire and the bracket under the influence of ligatures and the oral environment throughout orthodontic tooth movement. Among all orthodontic appliance components, brackets stay the most intraorally without replacement, if not throughout the whole treatment duration.[1]

Friction, in its two forms, is a force that impedes two objects in contact, from motion.[2] The static form resembles the force needed for movement initiation when objects are stationary. However, the dynamic or kinetic form of friction takes place when the objects are in motion, and it works on resisting this motion.[3] The nature of the surfaces coming in contact whether physically rough or smooth, treated chemically or not, or modified by any means is proportional to the magnitude of the frictional force (FF).[4] This is called the coefficient of friction and it is constant for each material surface and resembled by the equation $F = \mu N$, where F is the friction force, μ is coefficient of friction, and N is the normal force.[5] Therefore, friction can be appreciated between any two surfaces whether it is significant or not. Simply because even smooth surfaces have irregularities which can be seen on a magnified scale, and the friction happens at the heights of these irregularities.[6,7]

In 1986, ceramic brackets were introduced in orthodontics mainly to provide an alternative to the less esthetic stainless-steel (SS) brackets. However, their high friction coefficient can negatively affect the treatment. When compared to SS brackets, ceramic brackets show high frictional coefficient. Up to 40–60% of the force applied for dental movement can be lost to counteract the FF, leading to both a reduced efficiency of tooth movement and a longer treatment duration.[3,8,9] While some of the force applied is being lost as frictional resistance, the supporting structure of the tooth receives whatever remains to commence tooth movement. Hence, sufficient magnitude of force must be applied to allow the occurrence of biological tooth response.[7] In addition, minimal friction between the bracket–archwire–ligature interface is required for efficient tooth movement.[10] Consequently, it is evident that the bracket slot dimension and bracket slot roughness has a direct relation with the amount of friction generated which indirectly affects the treatment efficiency.

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Table 1: Bracket sample selection

Brand	*Code*	*Manufacturer*	*Bracket slot/prescription*	*Composition/crystalline structure*
Inspire ICE™	ICE	Ormco®, Orange, CA, USA	0.022-in MBT	MC alumina
Symetri Clear™	SC	Ormco®, Orange, CA, USA	0.022-in MBT	PC alumina
CLEAR™	CR	Adanta®, Gilching, Germany	0.022-in MBT	MC alumina
DISCREET™	DT	Adanta®, Gilching, Germany	0.022-in MBT	Clear hybrid (α-ceramic compound copolymers)
Victory series™	VS	3M Unitek, CA, USA	0.022-in MBT	SS

Previous studies have tested many variables that can affect the FF magnitude generated, which include (A) the archwire composition, dimensions and angulation in the slot,[8] (B) the bracket material, dimension, and surface texture, (C) the ligation (type and force), (D) the intraoral variables and the medium for testing: the saliva, plaque, bone density, root surface area, and occlusion, and (E) the bracket–wire angulation, the distance between brackets, the degree of discrepancy between adjacent bracket slots, applied retraction forces, and point of force application.[2,3,8,11,12]

It is well established that ceramic brackets generate higher FF when compared to SS brackets. Comparing mono- to polycrystalline (PC) brackets, FF is quite controversial. Some supported that PC ceramic brackets shows higher FF due to their rough surfaces.[13] Others have concluded that MC brackets have superior FF.[14] Furthermore, Pimentel et al. concluded that in the presence of saliva both PC and MC brackets showed similar FF.[15]

Adenta company has developed a new clear hybrid material composed of α-ceramic compound copolymers as described by the material safety and data sheet (MSDS). This material is a combination of different translucent materials including ceramic, released in DISCREET® brackets. Furthermore, DISCREET® is a one-piece-bracket manufactured with a unique laser aided sinter line technology. As claimed by the manufacturing company, clear hybrid material overcomes the deformation that accompanied composite brackets. It does not wear like common polyurethane and bicarbonate materials, and displays high material stability, without the brittle and abrasive characteristics when compared with PC and monocrystalline (MC) ceramics. However, to our knowledge these asserts have not been tested yet.

It was reported earlier that the alumina brackets showed significant increased smoothness after sliding.[16,17] Lee et al. also concluded that ceramic brackets have acceptable biological response and experience less friction, which would encourage effective tooth movement.[16] The resistance to sliding and its relation to the surface irregularities of the material have a great clinical impact on the efficiency of orthodontic treatment, thus, efforts were made to visualize its effect the archwire and bracket complex.

Various methods have been utilized in former research to assess the surface topography of brackets and archwires.[18] Scanning electron microscopy (SEM) offers a two-dimensional (2D) surface morphology for qualitative analysis.[4,19,20] The contact surface profilometer provides 2D surface roughness parameter values. A noncontact optical profilometer (3D interferometry profilometer machine) can be used to quantitatively evaluate the surface morphology of the bracket slot floor, giving a parameter value by measuring the surfaces height disparities using the light wavelength, without the need for sample preparation, and without causing any damage to the sample during testing (noninvasive).[4,19,20] Finally, atomic force microscopy (AFM) provides 3D quantitative measurements of the selected surface.[16]

A comparison between the classical types of brackets was seen in literature, however, none of them was compared to the new clear hybrid material. Therefore, the primary aim of the study was to assess the static friction (SF) and kinetic friction (KF) generated while sliding. Second, to analyze and compare the surface roughness before and after sliding of four different types of as received ceramic brackets (one PC bracket, two MC ceramic brackets, and a clear hybrid bracket) and a SS bracket that served as control, qualitatively and quantitatively using a SEM and noncontact optical profilometer. In addition, surface roughness and FF generated during the sliding was tested for correlation.

Materials and Methods

Sample Selection

In this analytic experimental *in vitro* study, five bracket systems were selected as presented in Table 1. Two MC ceramic brackets [Inspire ICE™ (coded as ICE); CLEAR™ (coded as CR)], one PC ceramic bracket [Symetri Clear™ (coded as SC)], one clear hybrid ceramic bracket [DISCREET™ (coded as DT)], and one metal bracket serving as control [Victory series™ (coded as VS). The level of significance was set at $\alpha = 0.05$, effect size of 20%, and power of 85%, therefore, each group has to have at least 18 brackets.

Specimen Preparation

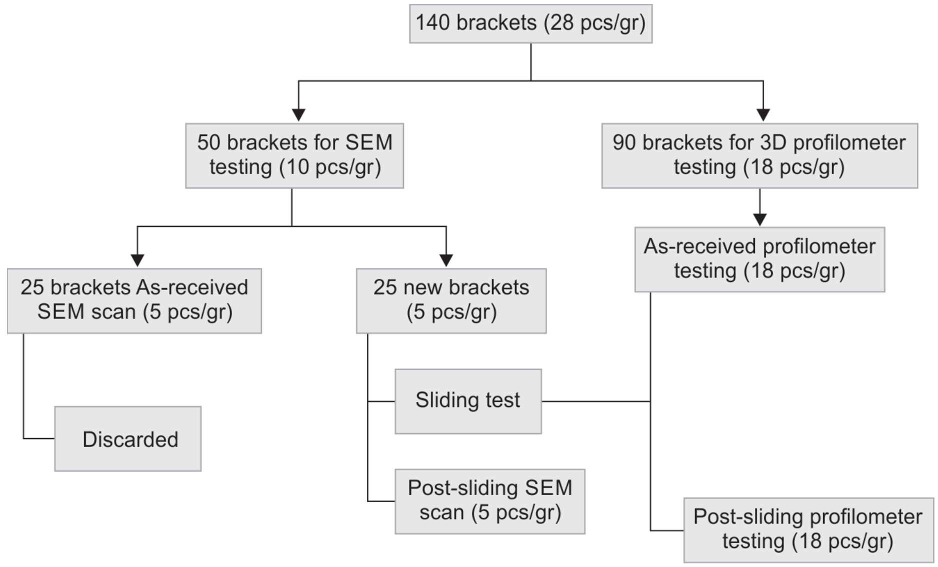
A total of 140 brackets were prepared for SEM analysis and optical profilometry evaluation. A prefabricated acrylic tooth crown was used to mimic the curvature of normal tooth anatomy of an upper right central incisor. The palatal part of the crown was mounted chemically on customized pink acrylic base using Interacryl Ortho powder and methyl methacrylate liquid (Interdent, Gornji Grad, Slovenia). To standardize the bracket placement in the center of the tooth a surveyor was used. Brackets were cemented using super glue (ALTECO Group of companies, Japan).

Following the as-received analysis, 115 brackets were subjected to a sliding test over a rectangular SS archwire with a 0.019×0.025-in cross-section (3M Unitek, Monrovia, CA, USA) to simulate clinical retraction mechanics during space closure. Later, all brackets were assigned for postsliding qualitative and quantitative analysis as described in Flowchart 1.

Bracket Surface Characterization Using Scanning Electron Microscope Analysis

The SEM sample preparation involved using a Fine Coat Ion Sputter machine (Ion Sputter JFC-1100, Tokyo, Japan). The purpose of this machine was to coat each bracket with gold before SEM scanning.

Flowchart 1: Bracket flowchart



A total of fifty brackets (10 brackets/group), were scanned by SEM (JSM 6360 LV, JEOL Ltd, Tokyo, Japan) using high vacuum chamber pressure at 10 kV. Half of which were evaluated as received and discarded. The other half were examined after the sliding test was performed. The SEM was used to obtain a qualitative topographical evaluation of the five tested brackets. A photomicrograph of the bracket was taken at 20× magnification to analyze the impact of its overall look. While an additional micrographs was taken 1000× magnification to evaluate its inner slot.[20]

Profilometer Three-dimensional Analysis

Optical profilometer analysis was performed on the five tested types of brackets (18 brackets/group). The area chosen to be examined was the distogingival side of the slot surface using Bruker Contour GTK (Bruker Nano GmbH, Berlin, Germany); an optical noncontact surface profiling system. The scanning area on the profilometer was approximately (0.7×1.0 mm^2) at 5× magnification. To maintain the accuracy of the measurements, the data was analyzed using Vision 64 application software (Bruker Nano GmbH, Berlin, Germany). Five surface roughness 3D parameters were determined by the machine including the arithmetic average height of the surface topography, also known as average roughness (Sa); root mean square of the surface topography (Sq); 10-point height of the surface topography (Ss); skewness of topography height distribution (Ssk); and kurtosis of topography height distribution (Sku). In this study, out of the five measurements, the most relevant parameter was the Sa value, which represents the average surface irregularities of the slot floor in all three dimensions shown as an average of microheights. Once the measurement was taken, the sliding test was completed at a 0° angulation bracket slot-wire combination.

Exposing the Samples to Sliding Using Instron Machine

The archwire sliding test was performed using Instron universal testing machine (Instron 5965, Instron Corp., MA, USA) in a dry environment.[10,19,21,22] A total of 115 (25 SEM samples and 90 profilometer samples) bracket–wire combinations (23 brackets/group) were carried out at zero-degree angulation. Each bracket/archwire combination was cleaned with isopropyl alcohol and air dried before testing. The archwire was engaged to the bracket with an elastic module (Ormco, Orange, CA, USA) just before each test. The sample was loaded on a customized holder (i.e., specifically designed to fit the base of the sample) fixed on the universal testing machine to tightly secure the base of the sample while performing the sliding test. During testing, the upper end of the wire was attached to the 5-kg loading cell of the Instron machine, while the lower end was left free to be clamped to a 150-gm weight (Fig. 1). This aimed to keep the wire straight parallel to the moving arm and free of twist or torsion. The archwire was dragged up through the bracket slot. The FF produced by each pair of wire and bracket was evaluated and recorded in grams. Test was done at a crosshead speed of 10 mm/min over a 10-mm of archwire.[19] Two types of FFs were recorded. The SF force was measured at the highest point at the FF–displacement curve. While the average of the data obtained three seconds after the SF was calculated as the KF force.[23] After each test, the bracket was carefully unloaded, and the archwire discarded. After that, a new bracket/wire combination was placed on the holder for testing.

Fig. 1: Demonstration of the sliding test using Instron universal testing machine

Table 2: Comparison between the mean (±SD) SF and KF values of the brackets

	FF								
	SF				*KF*				
			95% CI				*95% CI*		*ANOVA*
Variables	*Mean*	*SD*	*Lower bound*	*Upper bound*	*Mean*	*SD*	*Lower bound*	*Upper bound*	*p-value*
Bracket groups									
CLEAR™	303.238898[a]	54.890542	275.94247	330.53532	244.258215[a]	60.091141	214.37559	274.14084	0.004*
DISCREET	195.272253[b]	45.078617	172.85518	217.68932	133.812653[b]	45.078617	111.39558	156.22972	0.000*
Inspire ICE™	294.228193[a]	115.48011	234.85379	353.60258	281.861193[a]	115.48011	222.48679	341.23559	0.757
Symetri Clear™	220.961114[b]	73.192670	184.56326	257.35897	167.726414[b]	73.192670	131.32856	204.12427	0.036*
Victory series™	186.625097[b]	28.201659	172.60074	200.64945	175.952097[b]	28.201659	161.92774	189.97645	0.264
ANOVA									
p-value	0.000*				0.000*				

*Statistically significant difference. [a,b]Vertically, groups with similar letters have no statistically significant difference from each other ($p < 0.05$)

Subsequently, both SEM and optical profilometer analysis was performed on the five tested types of brackets. Sample preparation and evaluation was performed as described in the earlier sections.

Statistical Analysis

The SF, KF, and the Sa before and after sliding were the variables analyzed in this trial. Furthermore, statistical package for the social sciences (SPSS), version 25.0 (IBM Corp., Armonk, NY, USA) was used to collect and analyze the collected data. The level of significance was fixed at ($p \leq 0.05$).

For the friction test, intraexaminer reliability analysis was performed to overcome possible observer bias. Intraclass correlation coefficient (ICC) estimates at 95% confidence interval (CI) were calculated using SPSS. Intraclass correlation coefficient estimate was 0.8 indicating good reliability.

Both one-way analysis of variance (ANOVA) and multiple comparison statistics were applied. To compare the pre- and post-results for the slot roughness optical analysis, a paired *t*-test was applied.

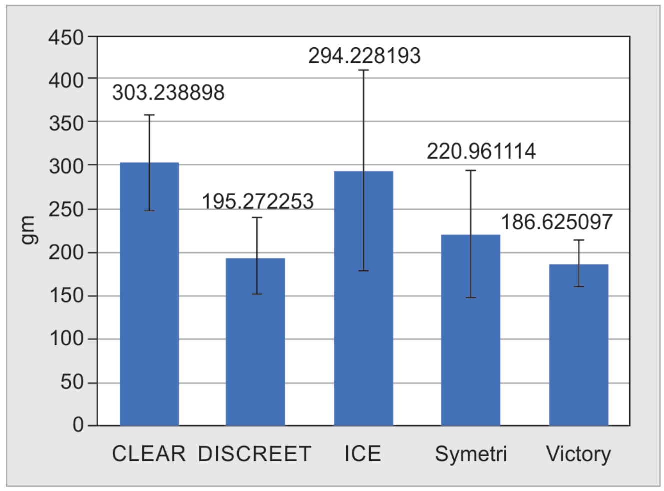


Fig. 2: Mean (±SD) static friction (SF) value of the brackets

Results

Static Friction and Kinetic Friction (gm)

The descriptive statistics [mean ± standard deviation (SD)] of SF and KF results were presented in grams (gm) in Table 2 and graphically illustrated in Figures 2 and 3.

Figure 2 shows that CR (303.24 ± 54.89) represented the highest SF value, followed by ICE (294.23 ± 115.48), SC (220.96 ± 73.19), and DT (195.27 ± 45.08). Victory series™ brackets (186.63 ± 28.20) came last showing the least SF value, yet there was no statistically significant difference between it, DT, and SC brackets. A one-way ANOVA showed a statistically significant difference in the SF values between the brackets ($p < 0.05$). Tukey's *post hoc* test showed statistically significant differences in SF values only between CR and DT; CR and SC; CR and VS; ICE and DT; ICE and SC; and ICE and VS ($p < 0.05$). No statistical difference between CR and ICE and between DT, SC, and VS.

The means and SDs of KF values are shown in Figure 3. ICE (281.86 ± 115.48) showed the highest KF value, followed by CR (244.26 ± 60.09), and VS (175.95 ± 28.20), SC (167.73 ± 73.19), and least in DT (133.81 ± 45.08). Using one-way ANOVA, a statistically significant difference in the KF values between the brackets ($p < 0.05$) was proven. Multiple comparisons statistics showed no statistically significant differences in KF values between CR and ICE, and between DT, SC, and VS.

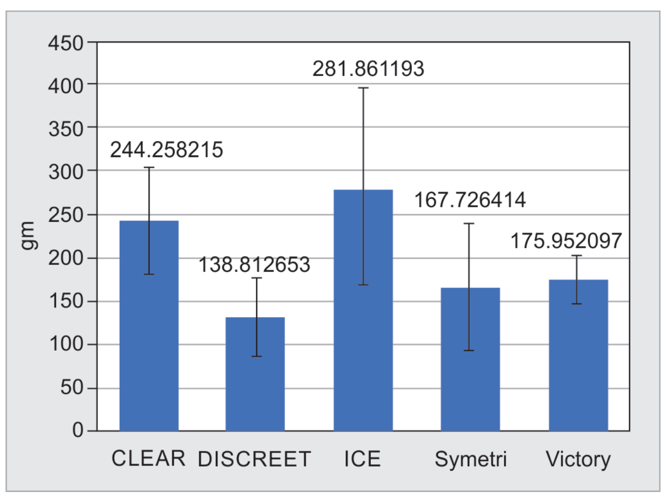


Fig. 3: Mean (±SD) kinetic friction (KF) value of the brackets

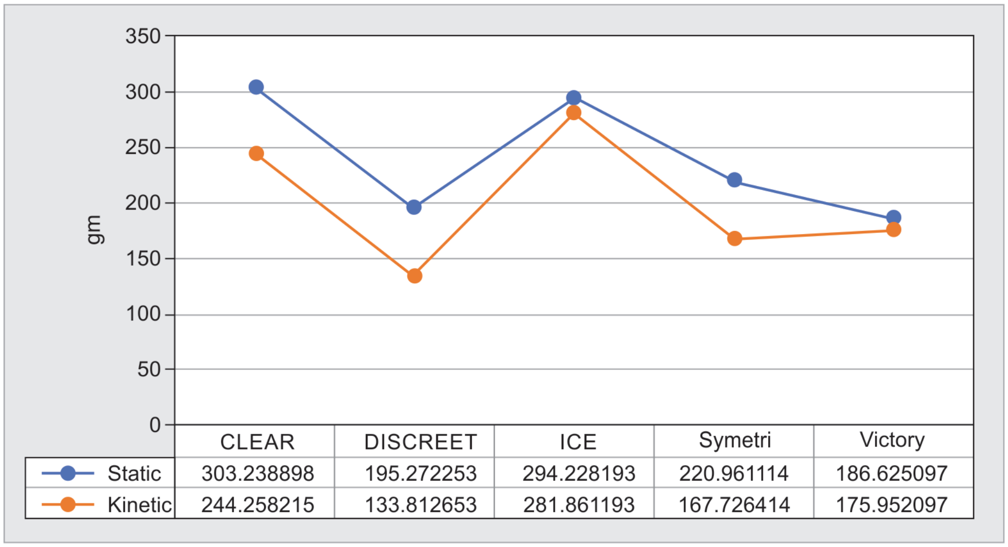


Fig. 4: The mean SF and KF friction values of the brackets

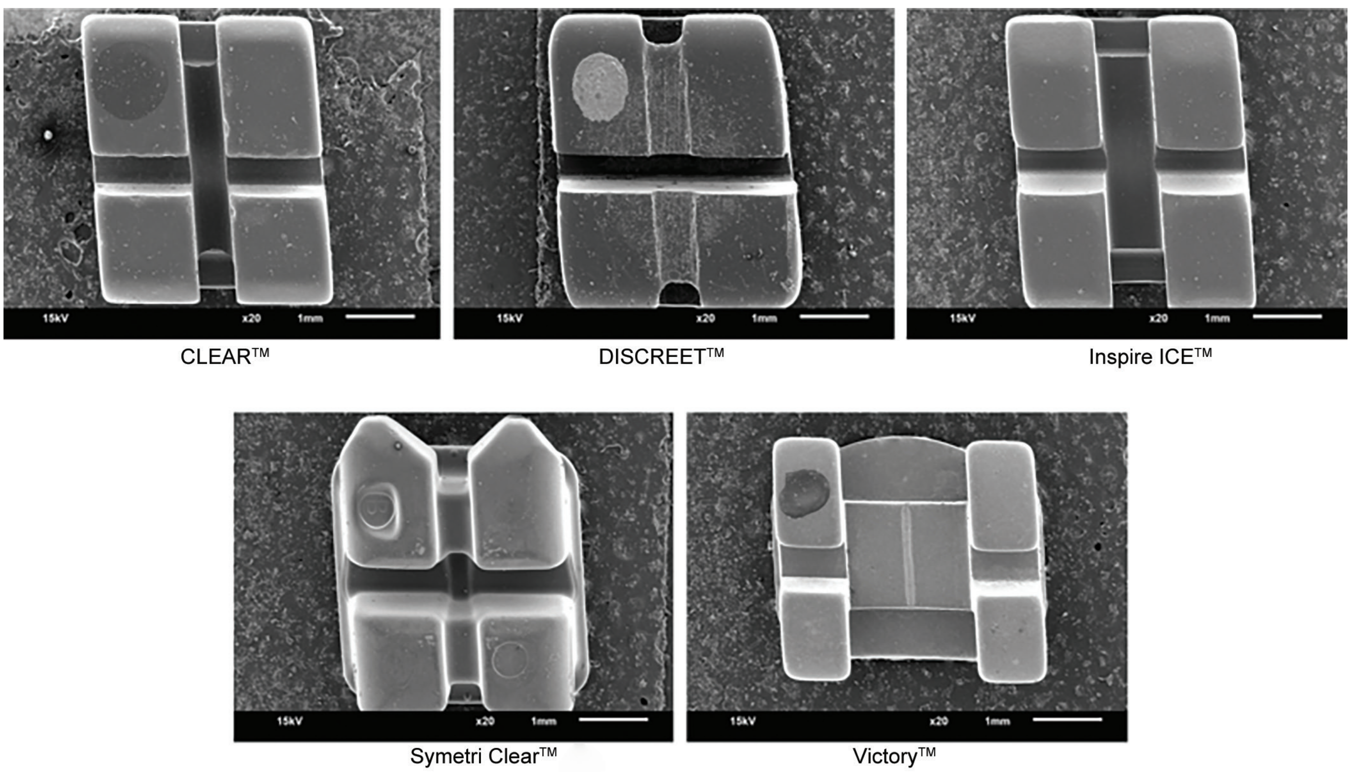


Fig. 5: Qualitative SEM surface topography images (20× magnification)

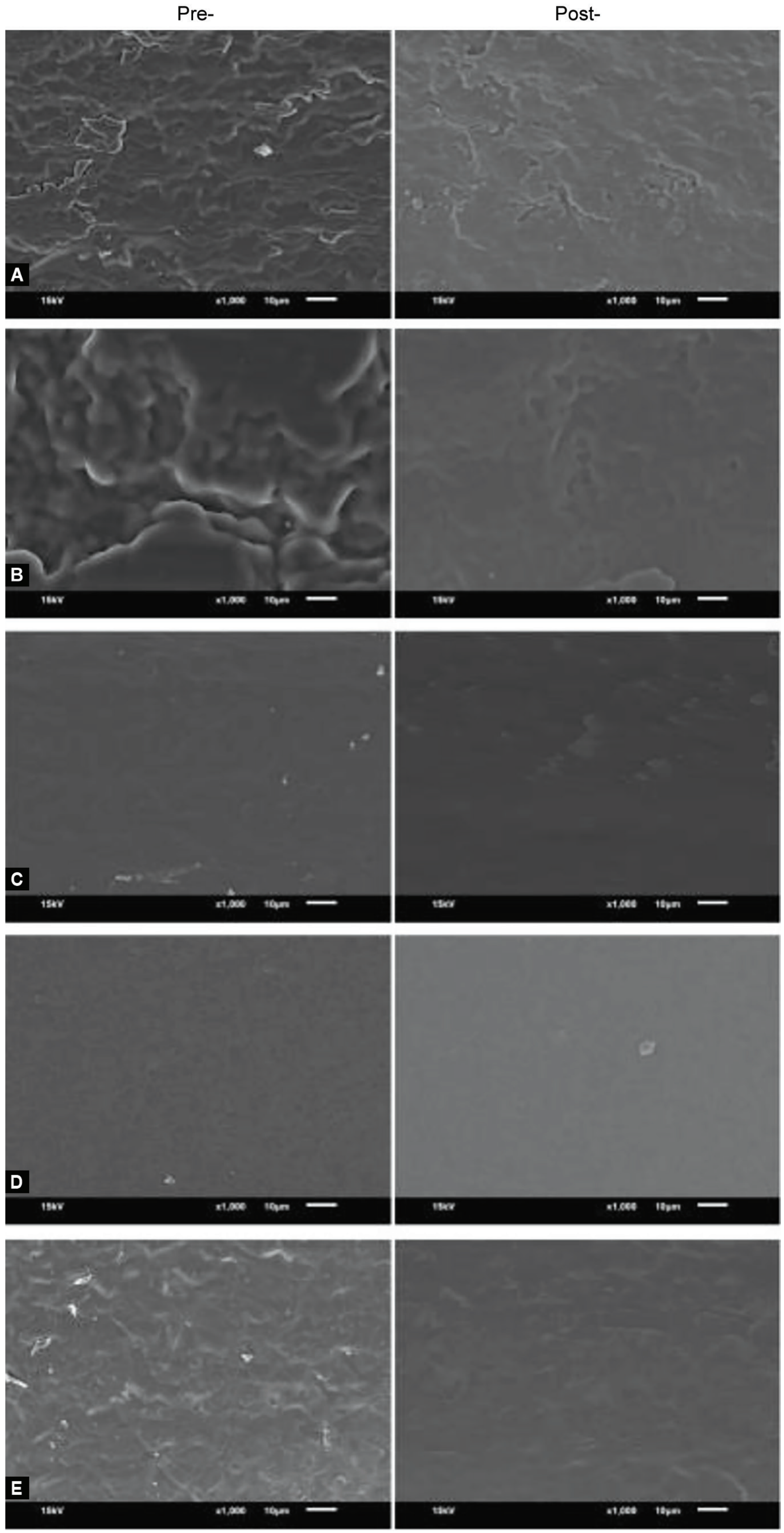
Comparison between Static Friction and Kinetic Friction Values (gm)

The mean (±SD) static friction values were higher than the KF values among all five brackets (Fig. 4). However, a statistically significant difference between the SF and KF mean values were found only in CR, DT, and SC ($p < 0.05$) (Table 2).

Qualitative Scanning Electron Microscope Surface Topography Analysis

Analyzing the 20× magnification, the surface topography of DT differed remarkably from the other three types of brackets (i.e., MC, PC, and metal), showing the greatest roughness followed by CR. SC appears to have the least irregularities on its surface and shows rounded corners when compared to MC (Fig. 5).

On the contrary, bracket slots were scanned at 500× and 1000× the original magnification showed that all brackets; including the SS bracket, had irregular slot floor surfaces before the archwire sliding test appearing as scratches, pockmarks, and facets (Fig. 6). After the arch-wire sliding test, minimal changes can be noticed. Surface details were observed on the surfaces of all brackets in pre- and postsliding images. However, it cannot be defined as obvious but surely still present even after sliding test.



Figs 6A to E: Qualitative pre- and post-SEM surface topography images (1000× magnification). (A) CLEAR™; (B) DISCREET™; (C) Inspire ICE™; (D) Symetri Clear™; (E) Victory series™

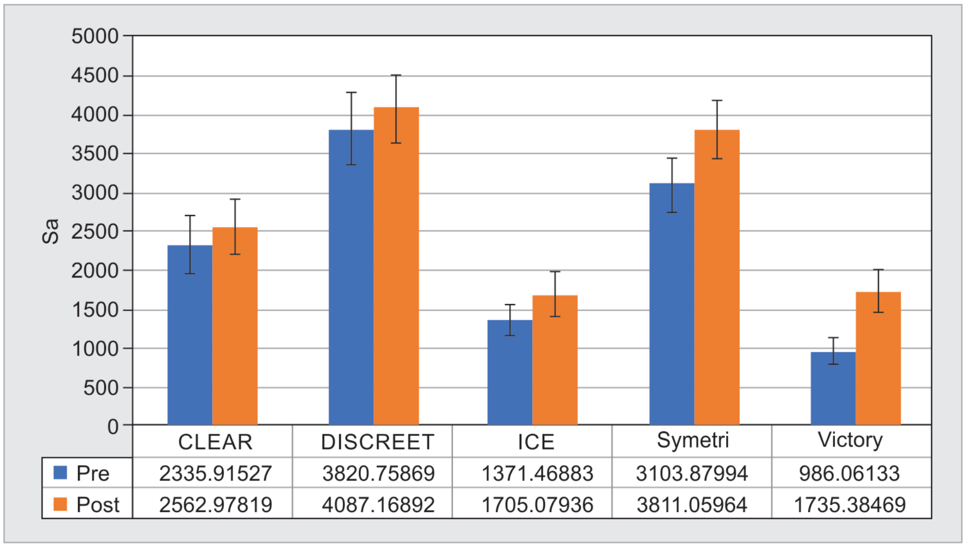


Fig. 7: Mean (±SD) pre- and postprofilometer surface topography

Table 3: Comparison of the mean (±SD) of pre- and postprofilometer surface topography

		Paired differences							
					95% CI of the difference				
		Mean	*SD*	*Standard error mean*	*Lower*	*Upper*	*t*	*df*	*p-value*
CLEAR™	Pre- and post	−227.0629	183.1826	30.5304	−289.0430	−165.0829	−7.437	35	0.000
DISCREET™	Pre- and post	−266.4102	227.7999	37.9666	−343.4866	−189.3338	−7.017	35	0.000
Inspire ICE™	Pre- and post	−333.6105	238.8216	39.8036	−414.4161	−252.8049	−8.381	35	0.000
Symetri Clear™	Pre- and post	−707.1797	292.0321	48.6720	−805.9892	−608.3702	−14.529	35	0.000
Victory series™	Pre- and post	−749.3234	217.3951	36.2325	−822.8793	−675.7675	−20.681	35	0.000

Table 4: Comparison of the mean (±SD) of pre- and postsliding profilometer surface topography

	Pre			*Post*		
	Mean	*SD*	*p-value*	*Mean*	*SD*	*p-value*
CLEAR™	2335.9152[a]	376.9619	0.000	2562.9782	349.5709	0.000
DISCREET™	3820.7587[b]	455.0673		4087.1689	442.9621	
Inspire ICE™	1371.4688[c]	193.4813		1705.0794[a]	291.4609	
Symetri Clear™	3103.8800[d]	336.2070		3811.0596	377.4094	
Victory series™	986.0613[e]	175.4310		1735.3847[a]	280.26397	

[a,b,c,d,e]Vertically, groups with similar letters have no statistically significant difference from each other ($p < 0.05$)

Symetri Clear™ appeared to have the least noticeable surface details.

Quantitative Profilometer Surface Topography Analysis (Sa)

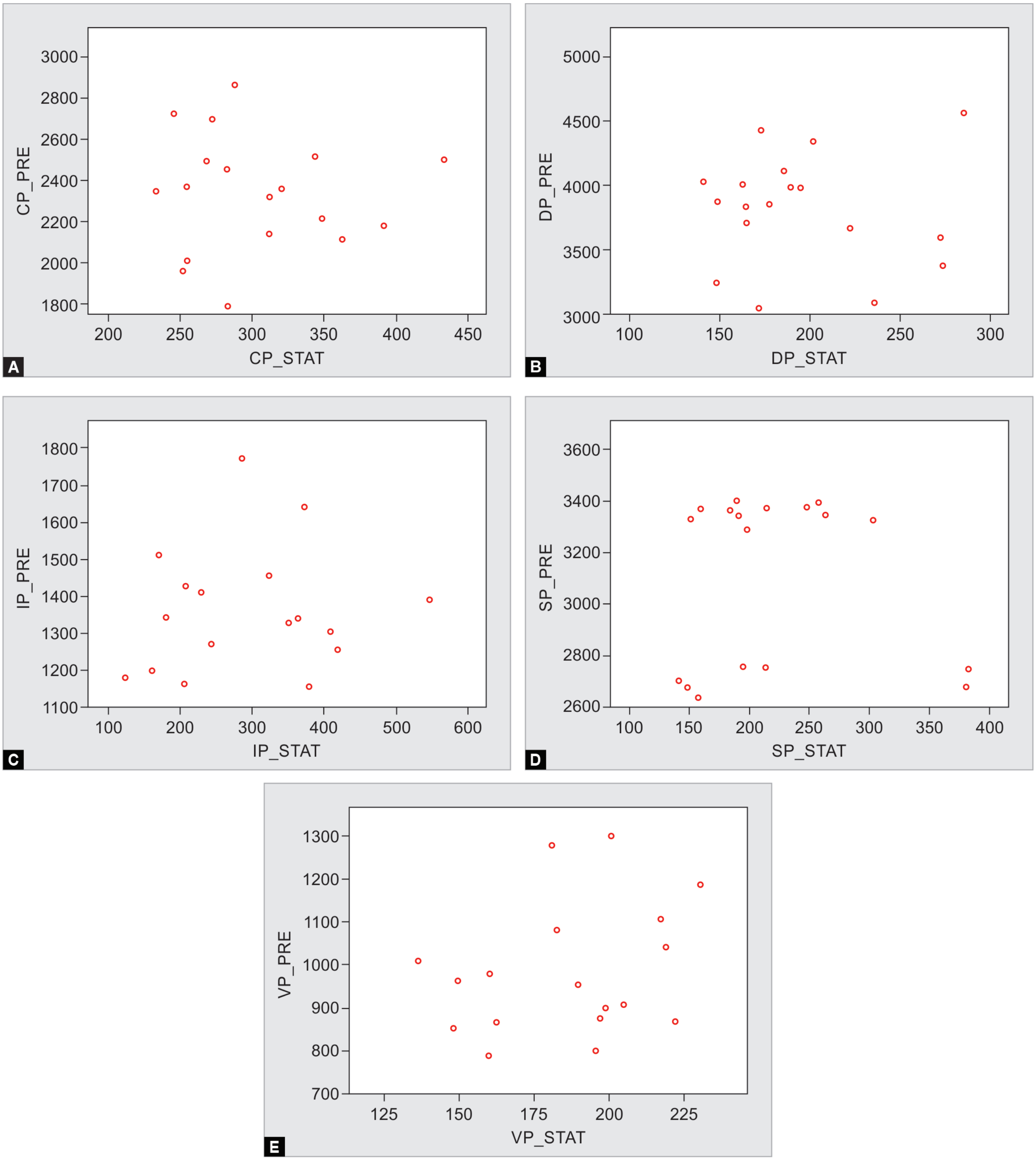
The means and SDs of pre- and postsliding profilometer surface topography values are shown in Figure 7. The mean postsliding profilometer surface topography values were higher than presliding profilometer surface topography values in all five brackets.

The mean difference between pre- and postsliding profilometer surface topography values were statistically significant in all five brackets ($p < 0.001$). Furthermore, the mean difference was highest in VS, followed by SC, ICE, DT, and least in CR (Table 3).

A significant difference in the surface topography values between the brackets, pre ($p < 0.05$) and post ($p < 0.05$), was statistically confirmed by using one-way ANOVA. Multiple comparisons showed statistically significant differences in the surface topography values between all as-received brackets ($p < 0.05$) and between all the brackets; post ($p < 0.05$) except for ICE and VS ($p > 0.05$) (Table 4).

Correlation Statistics between Frictional Forces and Surface Roughness

Pearson correlation was done between the SF and the presliding Sa value. The correlation statistics showed that none of the correlations were statistically significant ($p > 0.05$). It is represented by the



Figs 8A to E: Scatterplot represents Pearson correlation statistics between SF and surface roughness before sliding (Sa). (A) CLEAR™; (B) DISCREET™; (C) Inspire ICE™; (D) Symetri Clear™; (E) Victory series™

nonlinear relationship between the variables on the scatterplot (Fig. 8).

This study suggests that the surface roughness of the bracket slot might not necessarily reflect the amount of friction expected while sliding. In comparison to the control (SS) brackets, PC and clear hybrid ceramic brackets showed insignificant difference in the FF produced despite having considerable surface irregularities.

Discussion

Throughout the application of orthodontic biomechanics, tooth movement only happens when the magnitude of forces delivered surpass the FF at the bracket–wire interface. Bracket fractures, bonding failure, and minimal dental movement or even no movement at all can be observed when high levels of FF occur.[3] The aim of the current study is to evaluate the FFs generated during tooth movement, to evaluate and analyze the slot surface topography of different orthodontic bracket types (PC, MC, SS, and hybrid) and its impact on the amount of friction produced utilizing the SEM and the noncontact profilometer.

The methodology proposed for this trial was expected to control the variables influence on the results (i.e., consistency of slot size, bracket prescription, test speed, orthodontic wire characteristics, degrees of tip and torque). For standardization purposes, the brackets were chosen to be placed with zero degrees of tip and torque to allow the only classical friction to be tested (i.e., with no binding or notching). To ensure that the bracket material is the only tested variable, the elastic module and wire were unified in terms of material and size.

Two slot sizes are available in the markets from which the clinician may choose. In this study, 0.022-in-slot brackets were chosen over 0.018 in as greater number of studies has used 0.022-in slot in their samples.[4] According to McLaughlin, Bennett and Trevisi (MBT), the 0.022-in-slot size, provides larger slot which allows easier wire placement and facilitates more freedom of movement for the starting wires which keeps the forces light. Additionally, at later stages of treatment, the 0.019 × 0.025-in SS working wires seems to be more rigid allowing less deflection and less binding during retraction.[24]

The archwire used in this trial was 0.019 × 0.025-in SS wire. The wire dimensions were chosen as it is known to be the wire of choice during space closure when using 0.022-in slot brackets. It is also well established that FF are greater when rectangular cross-section wires.[25]

According to Tanne et al., ceramic brackets may induce greater wire scratches and surface wear while sliding due to their more porous and rougher slots which subsequently generates greater FFs hindering smooth tooth movement.[9] Therefore, a new wire segment for each bracket was used ensuring that it is not pulled more than once. All of which to ensure fair comparison of the different bracket type.

Regarding the FFs, the results of the current study showed that there was no statical difference in SF between CR and ICE, and between VS, DT, and SC. The later three brackets occupied the lower end of the scale. This categorizes the MC brackets regardless of their manufacturing company as the brackets generating higher frictional values when compared to the other types. These results come concurrent with what was reported by previous studies.[20,26]

Numerous papers have discussed the FFs generated during orthodontic treatment with several possible variations in the orthodontic appliance. Nevertheless, a controversy between the studies was perceived when comparing different bracket types. While some investigators concluded that MC alumina brackets created lesser FF when compared to PC alumina brackets, others reported no differences between the two ceramic types, the present study agrees with the majority of the studies that reported higher FF related to MC brackets when compared to PC ceramic brackets and metal ones.[15,19,20,26–28] Despite the inconsistency in the conclusion, MC ceramic brackets seems to have higher frictional values and have hardly ever been found to have lesser FF than SS or PC ceramic brackets.

The SF forces were generally greater than the kinetic ones in all bracket–archwire combinations. This validates the preceding studies which compared SF to KF.[21,29,30] However, in the present investigation, the difference was not significant as similarly stated by Cacciafesta et al. and Kapur et al. who concluded insignificant higher SF values when compared to KF values.[20,30]

Regarding the surface roughness, from the SEM images, it can be concluded that PC ceramic brackets appear to have smoother surfaces. This can be explained by the manufacturing process followed in each type. Monocrystalline brackets are engineered by milling the ceramic blocks to a bracket shape using diamond cutters while the PC brackets are constructed by injection-molding technique (i.e., melting raw material into molds) to produce desired shapes. Manufacturers usually tend to perform heat polishing process after milling process as it results in significantly greater surface roughness. However, MC brackets still have relatively high slot roughness values.[30] It was reported by Omana et al. that PC ceramic brackets exhibited smoother surfaces and less friction when compared to other brackets which reflects on the effect of manufacturing technique.[31]

Despite this, and since quantifying the irregularity value depends on the method used for measurement, then the examination protocol chosen is very critical. With the advancement of surface topography characterization techniques, SEM assessment of the surfaces' general appearance is considered not conclusive, quite unreliable and subjective.[32] Therefore, a noncontact optical profilometer was used. The profilometer evaluation offers a more consistent quantitative analysis.

Of the five 3D parameters given by the profilometer evaluation, the Sa was the value of interest. It represent an average of the surface heights of the bracket slot floor in three dimensions, taking the area as a whole into consideration unlike the (Ra) value which would represent the slot in two dimensions only.[4]

It has been previously reported that due to the inherent hardness of ceramics, alumina-brackets demonstrated a considerable reduction in surface roughness and an increase in smoothness after metal wire sliding. Accordingly, Lee et al. concluded that while in use ceramic brackets would aid in the effectiveness of tooth movement as it experiences less friction after sliding.[16,17]

In contrast, the results of the current study showed statistically significant difference between all as-received brackets. The quantitative profilometer (Sa) values of the tested brackets revealed that the as-received clear hybrid brackets (DISCREET) showed the highest surface roughness followed by PC, MC, and SS brackets in a descending pattern. Furthermore, in comparison to the as-received state, all brackets, regardless of material composition, demonstrated an increase slot floor surface roughness after the archwire sliding test (Fig. 7). This increase in Sa values was significant for all brackets except for ICE and VS (Table 4). Comparable results were formerly interpreted by previous similar studies.[19]

In 2014, Choi et al.[18] studied different brackets including metal, MC ceramic bracket, and three types of plastic brackets before and after archwire sliding. He concluded that with the assistance of SEM and 3D optical surface profilers, all types of brackets revealed irregular slot floor surfaces when tested as-received, and both the irregularity and roughness increased after the archwire sliding test. Compared with the performance of other bracket types, ceramic brackets showed significantly lower surface roughness values and higher frictional values during the archwire sliding test.[19]

It is expected that FF and SR have a direct relation, however, this inconsistent relationship between the bracket surface characteristics and the FF has been reported previously in multiple studies.[19,20,26] Several authors including Choi et al., Alsubaie et al., and Cha et al. who have evaluated the surface roughness of the MC ceramic brackets, included ICE brackets in their investigations. It was recognized that ICE brackets recorded the highest FF among the other brackets, although it had the least roughness in its slot surface.[19,26] Interestingly, in the present study as well, ICE brackets revealed the lowest roughness in its slots and scored the highest in friction values.

It has always been accredited that high friction in alumina brackets is related to their greater surface roughness surface. Contrary to what one may anticipate, higher frictional resistance does not correlate with a rougher slot surface. No clear relationship has been established between FF and the irregularities on the bracket's surface. A reasonable explanation for such a result would be the bracket slot geometry and design. As seen in Figure 5, CR and ICE brackets (i.e., MC ceramic brackets) had sharp right-angle edged wings vs smooth rounded edges in SC brackets. These edges form the roof and floor of the slots that engage with the sliding wire. Such physical characteristics were thought to exacerbate the binding and negate the advantage of smoother surfaces as described by previous researchers and can be applied to the present study as well.[19,20,33] Furthermore, chemically, the alumina (AL_2O_3) present in ceramic brackets might increase the adherence with SS wires as stated by Kusy et al.[34]

Perhaps the best combination for successful force delivery in critical anchorage cases would be SS wire in SS bracket because it is the most economical and has demonstrated the fewest clinical problems over time.[34]

The focus of this *in vitro* study was the changes in the surface topography and the FF caused by the sliding mechanics of the archwire through the bracket slots. However, clinically there is a collaborative effect from saliva, normal flora, oral hygiene solutions, in addition to the chemical interaction between the bracket–wire structural materials. If possible, it would be beneficial to simulate the dynamic effects of the oral environment in an *in vitro* setting.

Conclusion

The MC ceramic brackets appear to have the greatest FFs and the lowest surface roughness. DISCREET scored a very low frictional value comparable to metal brackets yet shows the highest surface roughness. All as-received brackets including both metal and esthetic ones showed a sort of irregularities in their slot surfaces, and this roughness increased after the archwire sliding test. There was no statistically significant difference between ICE brackets and VS in quantitative surface roughness evaluation postsliding. Furthermore, it was concluded that FFs produced during sliding were not correlated to surface roughness.

Clinical Significance

Friction is one of the inevitable hurdles that an orthodontist faces throughout the treatment. It prevents smooth tooth movements and reduces the treatment efficiency. Expecting the possible FFs produced during sliding mechanics helps the practitioner while brackets type selection, planning treatment mechanics (frictional vs nonfrictional), choosing the magnitude of force delivery, and the amount of tooth movement expectancy.

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