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Evaluation of Surface Roughness and Resistance to Sliding in Two Commercially Available Ceramic Self Ligating Brackets - An In vitro Study

By

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Dissertation submitted to

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(Deemed to be University) Chennai, Tamil Nadu

In partial fulfillment of the requirements for the degree of

Master of Dental Surgery

In the speciality of

Orthodontics and Dentofacial Orthopedics

Under the guidance of

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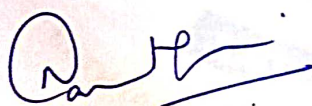
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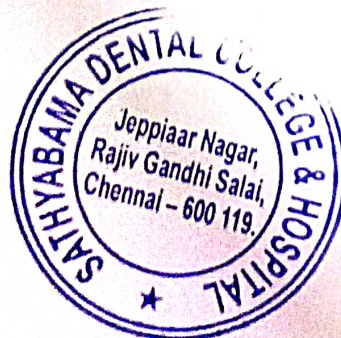
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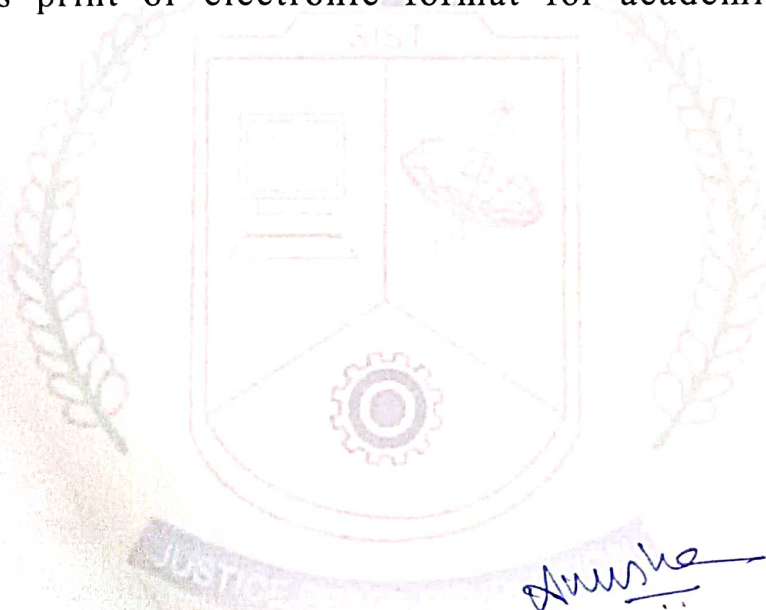
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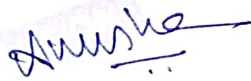
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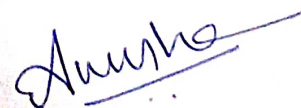
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I am pleased to inform you that the Institutional Human Ethics Committee (IHEC) has approved your project "**Evaluation of Surface Roughness and Resistance to Sliding in Two Commercially Available Ceramic Self Ligating Brackets- An In Vitro Study**" based on the presentation of the proposal made and recommendations of the IHEC committee meeting held on 30/10/ 2018.

The validity of this ethical clearance is for only one year till 30/10/2019 and in case if the study is not completed within the stipulated time they have to apply to renew for ethical clearance. You are expected to submit six monthly progress and final report of the study to the IHEC.

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INTRODUCTION

Tooth movement during orthodontic treatment is achieved by the orthodontic forces through brackets. Friction is defined as the force that opposes a movement when an object moves tangentially against another. It is the force that resists the movement of one surface past another and acts in a direction opposite to the direction of movement. During orthodontic treatment, friction is generated between the brackets and archwires¹.

Kusy and Whitley divided Resistance to Sliding (RS) into three components:

- Friction (static or kinetic)- Created when the wire contacts the bracket surfaces;
- Binding- Created when the tooth undergoes tipping or the wire flexes, so that there is contact between the wire and the corners of the bracket
- Notching- Created when permanent deformation of the wire occurs at the wire-bracket corner interface. Tooth movement halts when a notched wire catches on the bracket corner and continues only when the notch is released².

Fukui et al evaluated the influence of friction on orthodontic tooth movement (OTM) using the finite element method and reported that approximately 60% of the orthodontic force applied to a tooth is lost due to friction³. Thus, the biological tissue response to the mechanical stimulus occurs only if the force is large enough to overcome the force of friction. Therefore, higher levels of

friction during sliding mechanics require the application of higher orthodontic forces which may compromise the amount of OTM, complicate anchorage control⁴, increased treatment time and might cause root resorption⁵. This is contrary to what is recommended in orthodontics about the use of light forces to initiate and maintain tooth movement⁶. Because frictional force cannot be eliminated given that it is associated with every force applied to move the teeth, it should be minimised during the treatment⁷.

Resistance to sliding in orthodontics is influenced by various parameters such as bracket composition, archwire properties, interbracket distance, slot size, second order angulations, method of ligation, etc^{2,8,9,10}. Numerous methods to reduce friction was developed by altering the above parameters like use of stainless steel brackets, self-ligating brackets and surface treatments like polishing and sintering^{8,11,12}.

Due to increase in demand for esthetics in dentistry, orthodontic suppliers have been developing brackets made of different materials that are more esthetic than metal. Ceramic, polycrystalline or monocrystalline alumina and polycarbonate brackets have been manufactured to meet this demand. Nevertheless, ceramic brackets produce nearly twice as much friction compared to the stainless steel brackets^{13,14}. To overcome the increased friction of ceramic brackets, manufacturers have implemented various methods like incorporating metal slots, blunting the slot edges, and glazing their surfaces¹⁵.

Furthermore, friction was also influenced by the nature of ligation¹⁶. There are various modes of ligation such as stainless steel ligatures and elastomeric ligatures. For improving esthetics and reduce friction, newer elastomeric ligatures like silicone coated and polymer coated elastomeric ligatures were introduced. Khamatkar et al demonstrated that the least frictional force was seen in Teflon coated ligatures, followed by stainless steel ligatures and maximum in elastomeric ligatures¹⁷. In order to further reduce friction, a novel method called Self Ligating Brackets (SLB) were developed.

SLBs were first developed like a Russell attachment by Stolzenberg in the mid-1930s. The self-ligating bracket is provided with a metal clip, which holds the wire inside its slot and forms a tube-like structure¹⁸. The SLB can be divided into passive, active and interactive clips. A passive clip bracket does not push the wire into the slot whereas in an active clip, the wire is forced towards the slot floor. In interactive clip, smaller wires are captured passively and larger wires actively¹⁹. Faizee et al, in his study disclosed that in both passive and active groups, passive SLB had significantly lesser frictional forces compared to active SLB, whereas brackets with conventional ligation exhibited the maximum values for all the archwires tested²⁰.

The limit value where the passive configuration of the bracket and archwire becomes an active configuration is termed the critical contact angle². Thorstenson et al showed that for nominal wire and

bracket dimensions, the critical contact angle must lie between 0 and 4 degrees for sliding to occur. The resistances to sliding increased rapidly and nonlinearly when angulation increased above the critical contact angle as binding increasingly restricts sliding²¹.

Archwire is another parameter that influences resistance to sliding during OTM. Kusy and Whitley claim resistance to sliding is greater in wires of greater diameter because the critical contact angle is met with less tip in the bracket. Moreover, the larger wires are stiffer and there is a greater likelihood that the slot will cause notching of the wire²². Pizzoni et al showed that round wires had a lower friction than rectangular wires²³.

Another factor associated with the resistance to sliding that determines the efficiency of orthodontic tooth movement is the surface roughness of orthodontic appliance. Choi et al revealed that surface roughness can be considered an effective indirect method in estimating the frictional force of orthodontic appliances²⁴.

Manufacturers of the ceramic self-ligating bracket claim reduced resistance to sliding compared to conventional ceramic and metal SLB. Furthermore, frictional studies by varying bracket archwire angulation with round and rectangular archwires are very scant with these brackets.

Hence the aim of our study is to evaluate surface roughness and resistance to sliding of two commercially available ceramic self-ligating brackets by varying bracket archwire angulation with round and rectangular archwires.

REVIEW OF LITERATURE

Pertaining to our study, we will look at various studies that determine the influence of bracket material, angulation, archwire alloy, size and ligation

Andreasen G F et al²⁵ (1970) did a study to evaluate frictional forces in the edgewise bracket. Six archwires were tested for friction occurring between three brackets at four angles (0°, 5°, 10°, and 15°) placed between each wire and bracket. All the combinations are measured under both dry and with saliva acting as a lubricant. He concluded that saliva plays an insignificant role in lubricating the surfaces of the wire or bracket slot. Two explanations for this finding were offered. First, since not all substances act as good lubricants to all materials, perhaps saliva is not a good lubricant between the archwire and bracket slot under orthodontic conditions. Secondly, because the archwire touches the bracket at only two points, the lubricant could be expelled from the areas of contact allowing no lubrication between archwire and bracket.

Frank C A and Nikolai R J et al²⁶ (1980) compared the frictional forces generated in an experimental simulation of the canine-retraction procedure on a continuous arch wire. Six independent variables were chosen for study: arch wire size and shape, bracket width and style, second-order angulation between bracket and passive arch wire, arch wire material, ligature force and type of ligation, and interbracket distances. Frictional resistance

was found to be nonlinearly dependent upon bracket arch wire angulation. As angulations were increased, producing binding between wire and bracket, this variable itself became the controlling parameter.

Baker K L, Nieberg L G et al²⁷ (1987) determined the magnitude of frictional force changes between several sizes of stainless steel orthodontic wires (0.018 inch round, 0.020 inch round, and 0.018 × 0.025 inch rectangular) when an artificial saliva medium was introduced. The force values in the saliva substitute medium were compared with those produced in a dry control and in glycerin. Clinically significant differences among the environmental conditions and among the wire sizes were found. The introduction of saliva substitute provided a significant reduction of 15- 19% in force values.

Tidy D C et al²⁸ (1989) measured the frictional resistance by simulating tooth movement in a previously aligned arch. The effect of load, bracket width, slot size, arch wire size, and material were studied. He concluded that Nitinol and TMA arch wires give rise to significantly greater friction than stainless steel arch wire. The nitinol wire gives approximately twice the friction of a stainless steel wire of the same dimension, whereas TMA wire gives frictional resistance some five times greater than that of stainless steel wire. Also, round wires generally produced less friction than rectangular wire when engaged in brackets out of alignment because of their greater flexibility and less active torque.

Drescher D, Bourauel C et al⁶ (1989) constructed a three-dimensional model of tooth rotations to study factors affecting friction magnitude. The study concluded that for guiding a tooth along a continuous arch wire in an 0.018 inch bracket clinically, they recommend the use of medium (3.3 mm) or wide (4.2 mm) brackets, with 0.016 X 0.022 inch rectangular arch wire as a working arch to provide better spatial root control, the preclusion of wires with rough surface texture (TMA, nitinol) and the reinforcement of the anchorage units (e.g., extraoral) in maximal anchorage problems.

Popli K, Pratten D H et al²⁹ (1990) compared differences in magnitude of static frictional force generated by ceramic brackets (Allure, Unitek) stainless steel brackets (Unitek), in combination with nitinol and stainless steel arch wires (0.017 inch × 0.022 inch), in air and in artificial saliva. The results of this study showed that ceramic brackets provide significantly greater frictional resistance than stainless steel brackets when they were used in combination with either stainless steel or nitinol arch wires. He concluded that the significantly lower frictional resistance provided by stainless steel brackets is a result of their lower surface roughness, which was visible from scanning electron micrographs.

Kapila S, Angolkar P V³⁰ (1990) determined the effects of wire size and alloy on frictional force generated between bracket and wire. Stainless steel (SS), cobalt-chromium (Co-Cr), nickel-titanium (NiTi), and β -titanium (β -Ti) wires of several sizes were

tested in narrow single (0.050-inch), medium twin (0.130-inch) and wide twin (0.180-inch) stainless steel brackets in both 0.018- and 0.022-inch slots. The results revealed that β -Ti and NiTi wires generated greater amounts of frictional forces than SS or Co-Cr wires did for most wire sizes. Increase in wire size generally resulted in increased bracket-wire friction. The wire size-alloy interaction on the magnitude of bracket-wire friction was statistically significant. With most wire sizes and alloys, narrow single brackets were associated with lower amounts of friction than wider brackets.

Kusy R P et al³¹ (1990) evaluated friction in the dry and wet states for stainless steel, Co- Cr, Ni-Ti and beta titanium wires against SS and polycrystalline alumina brackets. He showed that the static and kinetic coefficients of friction were higher with polycrystalline alumina brackets than SS brackets. This is due to the surface roughness of the slot and because the nature of protective oxide layer which is different than SS material.

Bednar J R, Gruendeman GW et al⁷ (1991) conducted a study by simulating canine retraction to evaluate the difference in frictional resistance between stainless steel arch wires and steel and ceramic brackets with elastomeric, steel, and self-ligation. The results revealed that the self-ligating steel bracket did not demonstrate less friction than the elastic or steel-ligated stainless steel brackets. For most wire sizes, elastomeric ligated ceramic

brackets demonstrated the greatest friction when compared with other bracket/ligation technique combinations.

Ireland A J et al³² (1991) investigated the friction in buccal segment attachments during overjet reduction involving sliding mechanics. He compared friction in steel and ceramic brackets, using steel and nickel titanium wires of two sizes along with a new experimental polymeric wire. The results indicated that friction during overjet reduction is minimized by using larger dimension rectangular wires and by using steel rather than nickel titanium. On comparing steel with ceramic brackets, the latter show greater frictional resistance, but only when used with the smaller rectangular wires. The combined effect of environment, ligation, bracket, and archwire significantly reduced the difference.

Sims A P, Waters N E et al³³ (1993) did a study to evaluate the resistance to movement of sliding archwires through Activa brackets and compared these forces with SPEED and pre-adjusted Edgewise. Their results showed a significant reduction in frictional resistance in the Activa brackets compared with SPEED brackets by a factor of approximately 15. When the SPEED brackets were compared to Minitwin brackets, the reduction in friction was by 50-70 per cent. This indicate that self-ligating brackets require less force to produce tooth movement because they apply less frictional contact to the archwire than conventionally tied Siamese brackets.

Tselepis M et al¹³ (1994) studied dynamic frictional force of sliding between different modern orthodontic brackets and arch

wires. The factors involved in the frictional process like arch wire material, bracket material, bracket-to-arch wire angulation, and lubrication (artificial saliva) were selected. The results showed that the polycarbonate brackets has the highest friction and stainless steel brackets the lowest. Friction increased with bracket-to-arch wire angulation. Lubrication significantly reduced friction. A range of 0.9 to 6.8 N frictional force was recorded.

Vaughan J L et al¹¹ (1995) conducted an experiment to study the level of kinetic frictional forces generated during in vitro translation at the bracket-wire interface for two sintered stainless steel brackets as a function of slot sizes, wire alloys, and wire sizes. The results revealed that for most wire sizes, lower frictional forces were generated with the SS or Co-Cr wires than with the beta-Ti or Ni-Ti wires. Increase in wire size generally resulted in increased bracket-wire friction. There were no significant differences between manufacturers for the sintered stainless steel brackets.

Taylor N G et al⁴ (1996) did a study to compare friction of the brackets from “A company”, Activa brackets, and SPEED brackets. The study used round and rectangular wires of various dimensions. The results showed large frictional forces for wires secured with elastomeric ligatures in standard brackets. Elastomeric ligatures were found to decay over time. Stainless steel ligatures tied loosely on the premolar and Activa brackets produced the lowest frictional forces. The study suggested that there is a very little difference between static and dynamic friction. This indicated

that once initial tooth movement occurs, a relatively large force is required to maintain tooth movement.

Schumacher H A et al¹⁶ (1998) investigated the influence of differing but defined wire roundings on sliding mechanics of canine retraction. Employing the 0.018" slot system, 0.016" x 0.022" standard steel wires were tested. Force loss due to friction during canine retraction was determined using the Orthodontic Measurement and Simulation System (OMSS). In the arch guided distalization of canines, the average loss of force caused by friction was determined to be approximately 50%. Comparing wires with different edge bevel, the rounded wire in contrast to the wire with sharpest edge configuration results in a reduction of friction. Even a moderate wire rounding of the 0.016" x 0.022" steel wire results in about 10% reduction in frictional losses.

Pizzoni L et al²³ (1998) investigated the friction of self-ligating brackets against four wires: stainless steel and beta-titanium, both in round and rectangular cross-sections. The results show that round wires had a lower friction than rectangular wires, the beta-titanium wires had a markedly higher friction than stainless steel wires, and friction increased with angulation for all bracket/wire combinations. The self-ligating brackets had lower friction than conventional brackets at all angulations, and self-ligating brackets, closed by the capping of a conventional design, exhibited a significantly lower friction than self-ligating brackets closed by a spring.

Thomas S, Sherriff M et al³⁴ (1998) investigated the frictional characteristics of two types of self-ligating brackets (Damon and Time) and two types of pre adjusted edgewise brackets. Their results revealed that the Damon brackets produced lowest friction for all dimensions of test wires followed by Time bracket. Following self-ligation, standard twin brackets and then Tip edge brackets showed higher friction. Their results concluded that self-ligating brackets produce less frictional resistance than elastomerically tied pre adjusted edgewise brackets.

Articolo L C et al³⁵ (1999) studied the resistance to sliding (RS) as a function of five angulations (0° , 3° , 7° , 11° , and 13°) with stainless steel, single crystal sapphire, or polycrystalline alumina brackets against stainless steel (SS), nickel titanium (NiTi), or beta-titanium arch wires. In the passive configuration (determined to be at $\theta \leq 3^\circ$), RS was less in couples with SS wires than Ti wires, and RS was less in couples with SS brackets than ceramic brackets. In the active configuration, RS was less in couples with Ti wires than SS wires, and RS was less in couples with ceramic (PCA or SC) brackets than SS brackets. Binding component was first evident with the initiation of the active configuration at $\theta = 3^\circ$. Once the active configuration occurred and θ increased, the BI and FR components were additive in accordance with the principle of superposition.

Thorstenson G A, Kusy R P et al³⁶ (2002) investigated resistance to sliding for 3 self-ligating brackets having passive

slides (Activa, Damon, Twinlock) and 3 self-ligating brackets having active clips (In- Ovation, Speed, Time). 0.018 x 0.025-in archwire was tested under dry and wet states. The critical contact angles for binding were determined for all products and ranged from 3° to 5°. Below each characteristic critical angle, brackets with passive slides exhibited negligible friction. At second-order angulations that exceeded the critical angle, brackets with active clips that had a low critical angle had more resistance to sliding than did brackets with active clips that had a higher critical angle.

Cacciafesta V et al³⁷ (2003) measured and compared the level of frictional resistance generated between stainless steel self-ligating brackets, polycarbonate self-ligating brackets, and conventional stainless steel brackets, and 3 different orthodontic wire alloys: stainless steel, nickel-titanium, and beta-titanium. He reported that stainless steel self-ligating brackets generated significantly lower static and kinetic frictional forces than both conventional stainless steel and polycarbonate self-ligating brackets. Beta-titanium archwires had higher frictional resistances than stainless steel and nickel-titanium archwires. All brackets showed higher static and kinetic frictional forces as the wire size increased.

Tabakman V et al¹⁵ (2005) conducted a study to compare the frictional resistance in a new polycrystalline polymer self-ligating bracket (Opal, Ultradent), stainless-steel self-ligating bracket (Inovation, GAC), polycrystalline ceramic bracket with a heat-

glazed silicate slot along with recessed proximal slot edges (Mystique, GAC), ceramic with metal slot insert (Clarity, 3M/Unitek), and monocrystalline sapphire ceramic (Inspire,Ormco). The results indicated that the brackets had the following frictional resistance in increasing order: Opal, Inovation, Clarity, Mystique, and Inspire. Inspire bracket was significantly higher ($P < 0.05$) than the other brackets in this study.

Reicheneder C A et al³⁸ (2007) compared the frictional properties of two self-ligating aesthetic brackets, (Opal and Oyster), with those of four conventionally ligated aesthetic brackets (Transcend, Inspire, Allure and Image). Friction was tested with different wire dimensions and qualities(SS, TMA). He showed that both self-ligating aesthetic brackets had significantly lower friction than conventionally ligated aesthetic brackets with 0.017×0.025 and 0.019×0.025 inch SS wires. The Opal bracket produced the lowest level of friction for all bracket/archwire combinations.

Tecco S et al³⁹ (2009) tested the frictional resistance when round or rectangular archwires are used in conjunction with low-friction ligatures (small, medium, or large) or conventional ligatures. The results showed that low-friction ligatures demonstrated lower friction when compared with conventional ligatures when coupled with round archwires, but not when coupled with rectangular ones.

Krishnan M et al⁴⁰ (2009) compared the effects of stainless steel, nickel-titanium, and beta-titanium archwires on frictional

forces of passive and active self-ligating brackets with a conventional bracket. Friction was evaluated in a simulated half-arch fixed appliance on a testing machine. He reported that the contemporary designs of passive and active self-ligating brackets considerably reduce static and kinetic frictional forces compared with conventional brackets by approximately 75% and 50%, respectively. With the passive or active self-ligating brackets, stainless steel wire did not produce a significant difference, but differences were significant with nickel-titanium and beta-titanium archwires.

Cordasco G et al⁴¹ (2009) compared the treatment time when various modes of ligation were used. An in vitro set-up of three vertically unaligned brackets showed significantly lower frictional forces for passive self-ligation compared with elastic or metallic ligation demonstrated that treatment with passive self-ligating brackets resulted in a significantly shorter treatment time.

Reznikov N et al⁴² (2010) assessed the friction forces between passive self-ligating brackets (Damon2, SmartClip), active self-ligating brackets (In- Ovation) and conventional bracket (Victory- 3M Unitek) stainless steel orthodontic wires, subjected to different shear and bending forces in the buccolingual plane. In nonzero buccolingual deflections, passive selfligating brackets developed higher friction forces, comparable with those in the conventional elastic ligation control group. The degree of friction

resistance is proportional to the grade of the wire-securing elements' rigidity and to the extent of the wire deflection.

Stefanos S, Secchi A G et al⁴³ (2010) evaluated the frictional resistance between active (In-Ovation R, In-Ovation C and SPEED) and passive (SmartClip, Synergy R, and Damon 3mx) selfligating brackets and 0.019 x 0.025-in stainless steel archwire using an orthodontic sliding simulation device. Their results showed significant differences in both static and kinetic frictional forces among passive and active self-ligating brackets. The kinetic frictional forces associated with Smart-Clip, a passive self-ligating bracket, were not statistically different from those of In-Ovation C, an active self-ligating bracket. SmartClip acts as a passive self-ligating bracket when the archwire size is smaller than 0.019 x 0.025 in. At higher archwire sizes, some ligation force was exerted. Among the passive self-ligating brackets investigated, Damon3mx had the lowest frictional forces.

Doshi U H et al⁴⁴ (2011) conducted a study to determine the static frictional resistance between 3 modern orthodontic brackets: ceramic with gold-palladium slot, ceramic, and stainless steel and 4 archwires: stainless steel, nickel-titanium, titanium-molybdenum alloy (TMA), and low-friction colored TMA. The traditional ceramic bracket showed the greatest frictional values in all tested combinations and the ceramic with gold-palladium slot bracket showed the least frictional values. TMA wire showed highest, and SS wire showed the lowest, frictional values.

Husain N, Kumar A et al⁴⁵ (2011) determined the kinetic frictional resistance offered by stainless steel and Titanium bracket used in combination with rectangular stainless steel wire during in vitro translatory displacement of brackets. He used Dynalock (Unitek) and Mini Uni-Twin (Unitek)- 0.018'' slot, Ultra-Minitrim (Dentaurum), Titanium (Dentaurum) - 0.022'' slot with 0.016 x 0.022'' stainless steel and 0.017 x 0.025'' stainless steel (Unitek) wires. The results showed that narrow brackets generated more friction than wider brackets. Frictional force was directly proportional to wire dimension. Titanium brackets generated more friction than stainless steel brackets.

Brauchli L M, Senn C et al⁴⁶ (2011) compared the frictional behavior of several self-ligating brackets with that of normal brackets both with and without tipping force-moments of 0 and 10Nmm and in combination with different archwire dimensions. No resistance to sliding was found for any of the passive self-ligating brackets. The 10-Nmm tipping moment resulted in more RS and was similar for all bracket and archwire combinations. Resistance to sliding was approximately doubled when the center of rotation was located at the bracket rather than with a 10-mm offset.

Oliver C L et al⁴⁷ (2011) conducted a study to determine the frictional behavior of passive (CarriereSLB, ClaritySL, SmartClip, VisionLP), active (SPEED), and interactive (In-Ovation C) self-ligating brackets. He concluded that the resistance values associated with the four passive self-ligating bracket types remained 13–25

times lower than for the active SPEED bracket for all wire sizes and approximately 9–11 times lower than those generated by the interactive In-Ovation C bracket. The In-Ovation C bracket behaved similarly to passive self-ligating brackets with the smallest wire dimension tested. However, with the larger wires, it produced significantly higher frictional resistance behaving like an active self-ligating bracket. Wire depth played a more significant role in regulating the resistance to sliding of active or interactive brackets than wire height.

Thariq V K et al⁴⁸ (2011) conducted a study to examine the frictional forces generated by three types of self-ligating brackets ; two passive (Damon 3MX and Smartclip) and one interactive (Empower) when compared to conventional orthodontic brackets using two arch wire dimensions 0.016 NiTi wire and 0.019X0.025 inch stainless steel wire. He showed that self-ligating brackets had less friction when compared with conventional brackets with both round and rectangular wires. Of these, the passive self-ligating brackets, Damon 3MX shows the least friction when tested both with round and rectangular wires The frictional resistance of different groups in ascending order with 0.016 NiTi wire was Damon 3MX, Empower, Smartclip and conventional stainless steel brackets and with 0.019 x 0.025 inch SS wire was Damon 3MX, Smartclip, Empower and conventional stainless steel brackets. All brackets showed higher frictional forces as the wire size increased.

Faizee K S et al²⁰ (2011) conducted a study to evaluate the kinetic frictional resistance of four self-ligating brackets: Two active types, (Speed TM and In-Ovation® R) two passive types (Damon 3 and SmartClip) and compare them with conventional brackets ligated with elastomeric module. The brackets were tested against five different dimensions of round and rectangular stainless steel wires. The results showed that Damon 3 brackets exhibited least kinetic frictional resistance followed by SmartClip, In-Ovation and Speed respectively. Maximum resistance was recorded for conventional twin brackets ligated with elastomeric modules. There was an increase in the frictional resistance as the wire dimensions increased.

William C L et al⁴⁹ (2013) investigated the static frictional resistance at the bracket/archwire interface in passive SL ceramic bracket (Mystique), metal slot ceramic bracket system (Clarity) and compare them to conventional ceramic and conventional metal bracket systems. He showed that the metal bracket and metal slot ceramic bracket had lower frictional forces than the conventional ceramic bracket. Conventional metal had a significantly higher frictional force than both the metal slot ceramic and self-ligating ceramic using rectangular wires at 0° angulation. Rectangular wires showed a significantly higher frictional force value than round wires for metal and metal slot ceramic bracket systems. Increasing wire angulation significantly increases resistance to sliding at the bracket/archwire. The mean frictional force was approximately

twice its value for the 7° archwire angulation compared to the 0° archwire angulation.

Kumar S et al⁵⁰ (2014) compared the frictional resistance which was produced between conventional brackets (0.022 slot Otho-Organiser) and self-ligating brackets (active Forestadent and passive Damon III) by using various arch wires. His results showed that self-ligating mechanisms produced lower frictional forces than elastomeric ties. Forestadent Active self-ligating bracket system demonstrated higher friction than Damon III passive self-ligating system, which was probably related to special spring design. Friction appears to increase as archwire diameter increases. With all three bracket types, the 0.019 x 0.025 inch stainless steel wire produced the highest friction.

Monteiro M R e al⁵¹ (2014) conducted a study to compare the influence of archwire material (NiTi, beta-Ti and stainless steel) and brackets design (self-ligating- Smartclip, 3M/Unitek and conventional- Gemini, 3M/Unitek)) on the frictional force resistance with three (0, 5, and 10 degrees) slot angulation attached with elastomeric ligatures (TP Orthodontics). His results showed that self-ligating brackets (Smartclip) exhibited lower friction force when combined with nickel-titanium, stainless steel, and beta-titanium wires, in this order. A possible explanation is the fact that Smartclip has nickel-titanium clips, which in contact with wires of the same material could produce lower frictional values. Their results demonstrated that frictional values were statistically

significant and directly proportional to the increase in angulation, both in conventional and self-ligating brackets. Even at different angulations, the self-ligating brackets showed significantly lower friction force values than the conventional brackets.

Pillai A R et al⁵² (2014) did a study to evaluate the frictional resistance generated by conventional stainless steel, radiance ceramic bracket, self-ligating and composite brackets. The result of this study revealed that the overall frictional resistance of self-ligating PEA brackets was the least when compared to other brackets. The frictional resistance of ceramic brackets was the most, composite brackets are having less friction when compared to conventional stainless steel and ceramic brackets whereas conventional stainless steel brackets are having less friction than ceramic, but more than composite.

Lee S M, Hwang C J et al¹ (2015) compared the frictional force (FR) in self-ligating brackets among different bracket-archwire angles, bracket materials, and archwire types. Passive and active metal self-ligating brackets and active ceramic self-ligating brackets were included as experimental groups, while conventional twin metal brackets served as a control group. The FR was measured at 0°, 5°, and 10° angulations. His results showed that ceramic brackets exhibit a higher FR than metal brackets. With regard to FRs according to the bracket-archwire angle, the rate of increase in FR was greater when the angle increased from 5° to 10° than when the angle increased from 0 ° to 5 °. With regard to active self-

ligating brackets, the FR was similar in the ceramic and metal brackets when a round archwire was used, while it was lower in the ceramic brackets when a rectangular archwire was used.

Kannan M S et al⁵³ (2015) did a study to evaluate the frictional forces generated between fully esthetic brackets (Damon clear, Opal) and semi-aesthetic self-ligating brackets (Clarity SL, Damon 3), which are of passive form and SEM (scanning electron microscope) study of the Brackets after Frictional evaluation. He noticed that for each wire used, Damon 3 displayed significantly lower frictional forces than any of the self-ligating system, followed by Opal which generated smaller amount of frictional forces but relatively on the higher side when compared with Damon 3. Damon clear generated the maximum amount of kinetic forces with all types of wire dimensions and properties when compared to the other three types of self-ligating system. Clarity SL generated smaller amount of frictional forces when compared with Damon clear and relatively higher amount of frictional forces when compared to Opal and Damon.

Khamatkar A et al¹⁷ (2015) carried out a study to evaluate the effects of different ligature materials (stainless steel ligature, elastomeric ligature, Teflon coated stainless steel ligatures) on friction in sliding mechanics and to compare the effect of environment (dry and wet) on friction produced in sliding mechanics. The results showed that the mean frictional force of different groups in a dry state was statistically significantly higher

than wet state in elastomeric group. Teflon coated stainless steel ligatures produced the least friction among the materials tested in both dry and wet conditions.

Choi S, Hwang E Y al²⁴ (2015) investigated the relationship between the surface roughness and frictional resistance of four archwire and bracket combinations consisting of the 0.016-inch NiTi and 0.019X0.025-inch stainless steel archwires interacting with active-type Clippy-C ceramic self-ligating brackets, and passive-type Damon stainless steel self-ligating brackets, using the lateral force microscopy technique. He demonstrated lower surface roughness and frictional resistance in the interactions between NiTi and SS archwires and the Damon SS-SLBs (passive-type) as compared to interactions with the Clippy-C CE-SLBs (active-type).

Vale F et al⁵⁴ (2016) compared the resistance to sliding generated by conventional, active self-ligating and passive self-ligating brackets with stainless steel and nickel-titanium wires and to evaluate the effects of binding. The results revealed statistically significant higher resistance to sliding is observed in conventional brackets comparing to self-ligating brackets. No statistically significant differences were found between passive and active types and between archwire alloys at 0° angulations. At 5°, stainless steel showed statistically significant higher resistance to sliding. No statistically significant differences were found between 0° and 5° of bracket tipping.

Agarwal C O et al⁵⁵ (2016) investigated the surface roughness of four different commercially available stainless steel brackets- Gemini, 3M, Mini 2000,Ormco Corp., Opti-MIM, Ortho Organizers, Mini master, AO. The bracket slot floor was assessed with the scanning electron microscope (SEM) machine and a three-dimensional (3D) non-contact optical surface profilometer machine. The results showed maximum surface roughness for Gemini, followed by Opti- MIM, Mini 2000 and Mini master.

Hirunyapanun N et al⁵⁶ (2017) conducted a study to evaluate the frictional force level among self-ligating ceramic brackets (Empower Clear) compared with conventional ceramic brackets (20/40™ Ceramic), self-ligating stainless steel brackets (Empower metal), and conventional stainless steel brackets (Master) from Americal Orthodontics company. He showed that the self-ligating metal brackets produce the lowest frictional force followed by self-ligating ceramic, conventional metal and conventional ceramic brackets, respectively. Considering the mode of ligation, the results demonstrated that self-ligating metal and ceramic brackets produce significantly lower frictional force than conventional metal brackets conventional ceramic bracket, respectively. Concerning the bracket material, self-ligating metal conventional metal brackets yield significantly lower frictional force compared to self-ligating ceramic and conventional ceramic brackets, respectively.

Sunda S et al⁵⁷ (2018) did a study to evaluate and compare static and kinetic friction of round (0.018") and rectangular (0.019

× 0.025") stainless steel (SS) wires of different brands with conventional preadjusted edgewise brackets. The results revealed that the static friction was found to be greater than kinetic in all wires; 0.018" SS (3M) wire exhibited minimum static and kinetic friction; while 0.019 × 0.025" SS (3M) exhibited maximum static friction. The study concluded that 0.018" SS (3M) is better for individual canine retraction than the other wires used in the study because it has the least frictional resistance.

Kim K S et al⁵⁸ (2019) analysed the surface composition roughness and relative friction of metal self-ligating brackets (mini-Clippy, Tomy) from various ceramic self-ligating brackets- Clippy-C (Tomy), Empower clear (American Orthodontics), MACH (World Bio Tech), QuickKlear (Forestadent), and WOW-A® (Hubit). Atomic force microscopy-lateral force microscopy and scanning electron microscopy-energy-dispersive X-ray spectroscopy were used to analyse the surface of each bracket clip. There were no significant differences in the surface roughness and relative friction between the outer and inner surfaces of the uncoated clip and those of the control mC clip. Rhodium-coated clips, except the CC clip, exhibited rougher surfaces and a higher relative friction on the outer and inner surfaces compared to the control mC clip.

MATERIALS AND METHODS

This study has been approved by Institutional Review Board of Sathyabama Institute of Science and Technology:

Ref no:Sathyabama Dental College and Hospital/IHEC/study no. 063

The various materials, apparatus and the methodology used in the study are enumerated and briefly described below:

A. BRACKETS USED IN THE STUDY (Figure 1)

- Ceramic passive self-ligating bracket- Upper right 1st premolar (0.022" slot MBT)- Clarity Ultra, 3M Unitek, USA
- Ceramic interactive self-ligating bracket- Upper right 1st premolar (0.022" slot MBT)- Empower clear, American Orthodontics, USA
- Stainless steel conventional bracket- Upper right 1st premolar (0.022" slot MBT)- Victory, 3M Unitek, USA

B. WIRES USED IN THE STUDY (Figure 2)

- Stainless steel straight wire- 0.018" - G & H Orthodontics, IN, USA
- Stainless steel straight wire- 0.019 X 0.025" - G & H Orthodontics, IN, USA

C. ARMAMENTRIUM (Figure 3)

- Elastomeric ligatures- G & H Orthodontics, IN, USA
- Cyanoacrylate adhesive (Locite 401)
- Teflon blocks

D. Mounting device (Figure 4)

E. 3D Optical Profilometer- ContourX- 100, Bruker 3D surface measurement, Germany (Figure 5a)

F. Universal testing machine- Associated Scientific Engg Works with FIE Software, India (Figure 6)

STUDY DESIGN:

In vitro study

NULL HYPOTHESIS:

The null hypothesis is that there is no difference in surface roughness and resistance to sliding among selected ceramic self-ligating brackets and conventional metal brackets.

EVALUATION FOR SURFACE ROUGHNESS:

20 brackets from the three bracket variants (60 brackets in total) was tested for surface roughness. Each group was evaluated for roughness in the floor of the bracket slot with the help of a 3D non-contact optical surface profilometer machine at 40 X magnification. The measurement of the slot surface roughness was analysed by Vision (Bruker) software from which 3D and 2D surface texture parameters values were recorded in nanometer.

Each sample was placed on the flat surface of the profilometer machine with the help of a tweezer, under the beam of the white light interferometry (He-Ne, 633 nm). The beam of light is allowed to pass through the midpoint of the slot base and the reflected light is measured for surface roughness (Fig. 5b)

Surface roughness is measured as the surface elevation in z axis as a function of x and y over the same area. Surface topography was traced to quantify the roughness without damaging the slot surface. The Roughness average value Ra, represent the average of the differences in the mean height for the z-axis of the scanned area (Figure 7).

EVALUATION FOR RESISTANCE TO SLIDING

The brackets used in the experiment were categorised into 6 groups based on their interaction with the different stainless steel (SS) archwires (0.018" and 0.019 X 0.025").

- Group 1- 3M Clarity Ultra (Passive) SLB with 0.018" SS archwire
- Group 2- 3M Clarity Ultra (Passive) SLB with 0.019 x 0.025" SS archwire
- Group 3- AO Empower clear bracket (Interactive) SLB with 0.018" SS archwire
- Group 4- AO Empower clear bracket (Interactive) SLB with 0.019 x 0.025" SS archwire
- Group 5- 3M Victory (Conventional metal- control) with 0.018" SS archwire
- Group 6- 3M Victory (Conventional metal- control) with 0.019 x 0.025" SS archwire

All the groups were checked at 0 degrees and 10 degrees of bracket archwire angulation. A total for 20 testings (10 for 0° + 10 for 10° angulation) was done.

To mount the bracket, a laboratory device was designed and manufactured with the help of Engineering and Design Department, Indian Institute of Technology, Madras.

MOUNTING DEVICE DESIGN (Figure 4)

A cylindrical steel block is attached perpendicularly to a rectangular metal slab. The cylindrical block can be rotated with the axis of rotation at the center. The block is indexed for different angulations (Fig. 8). This angulation simulates the tipping of the bracket. The cylindrical block has a well within its center onto which Teflon blocks can be inserted.

Teflon blocks can be screwed into the well to hold it tightly. Bracket is bonded on the center of the Teflon block with a cyanoacrylate adhesive (Locite 401). The Teflon block is detached and a new block is placed for each testing sample.

The bracket mounting device was transferred to the Universal Testing Machine. Each bracket archwire sample was tested at two angulations: 0° and 10° respectively. 0.018" SS wire which has a length of 120mm was taken and placed within the bracket such that 20mm lies towards the lower jaw of the UTM, remaining length above the bracket. The lower part of the wire was crimped and upper part was attached to the UTM. The point of contact of the wire with upper jaw of UTM was at 100mm. This measurement was kept standard for every testing sample. In case of self-ligating brackets, the clip was closed and in the control group, elastomeric ligature modules were placed. The Teflon blocks can be rotated for

0 degrees and 10 degrees, simulating a tipping movement. Once a bracket wire sample at both angulation was checked, next Teflon block bonded with another bracket and engaged with a different wire sample was inserted for testing (Figure 9a, 9b, 9c)

The resistance to sliding was evaluated under dry condition and at a room temperature of ($24\pm 2^{\circ}\text{C}$) by means of a Universal testing machine (Figure 10). The load cell that recorded the frictional force at the bracket- archwire interface was 100N and the crosshead speed of 5mm/min for 2 minutes was given. A total of 120 testing were done, i.e., 20 brackets (10 in 0° and 10 in 10° angulations) in 6 groups were recorded.

FIGURES

Figure 1: Brackets Used in the Study

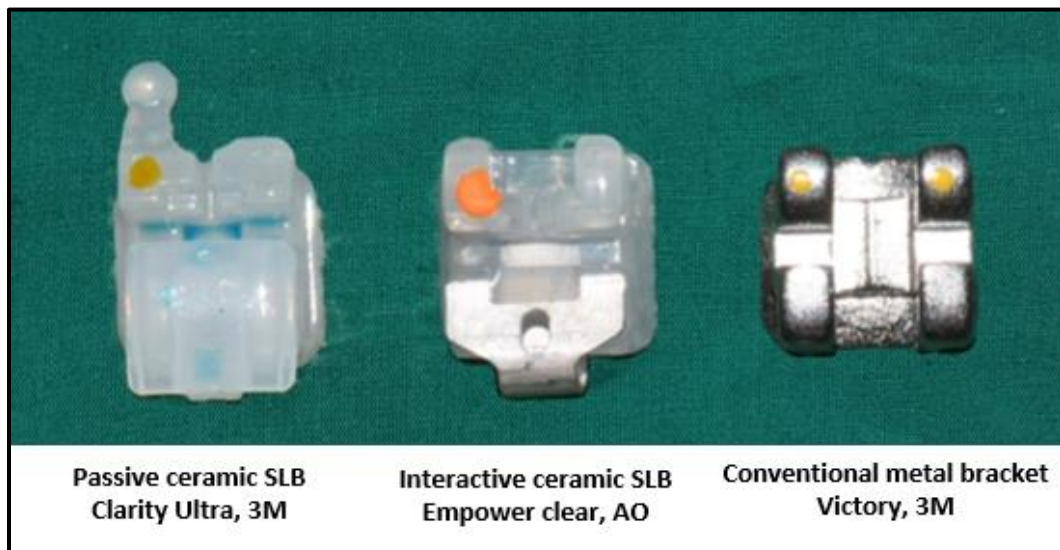


Figure 2: Wires Used in the Study

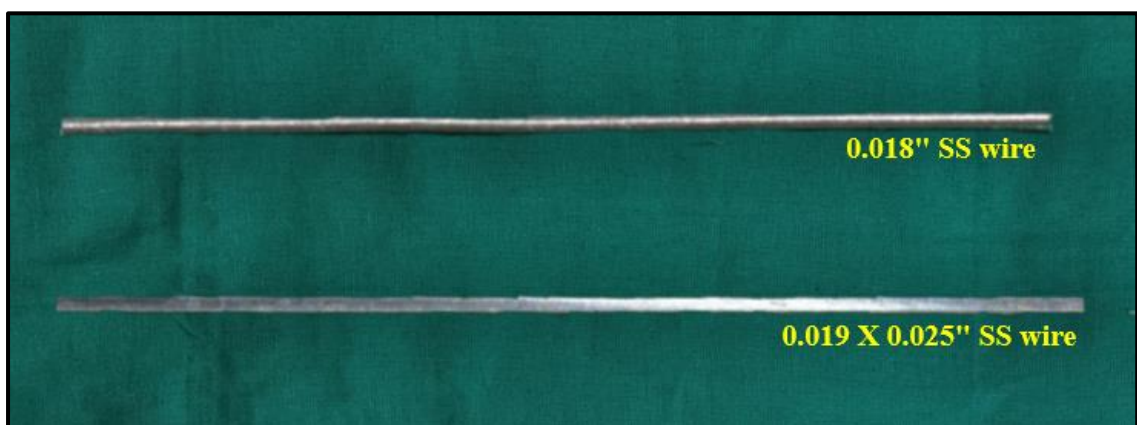


Figure 3: Armamentarium for Bonding



Figure 4: Mounting Device

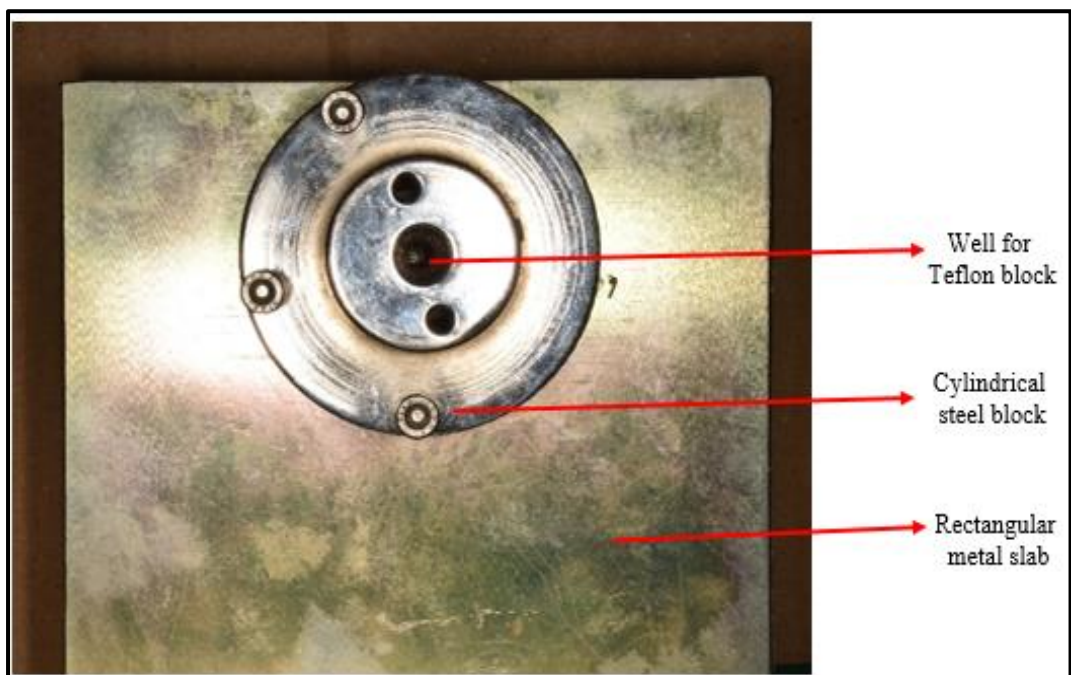


Figure 5a: 3d Non-Contact Optical Profilometer

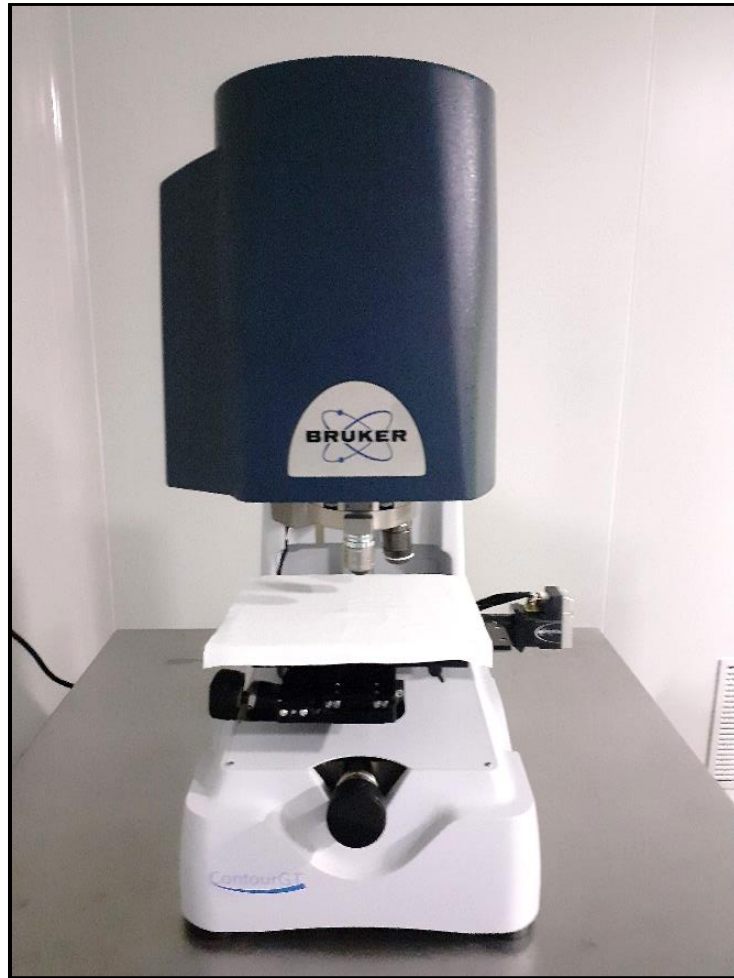


Figure 5b: Bracket under 40X Magnification

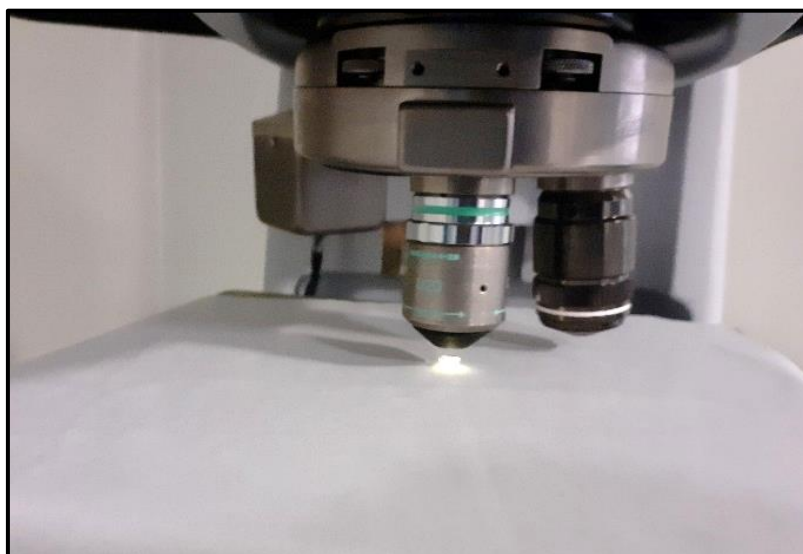


Figure 6: Universal Testing Machine



Figure 7: Surface Data from 3D Profilometer

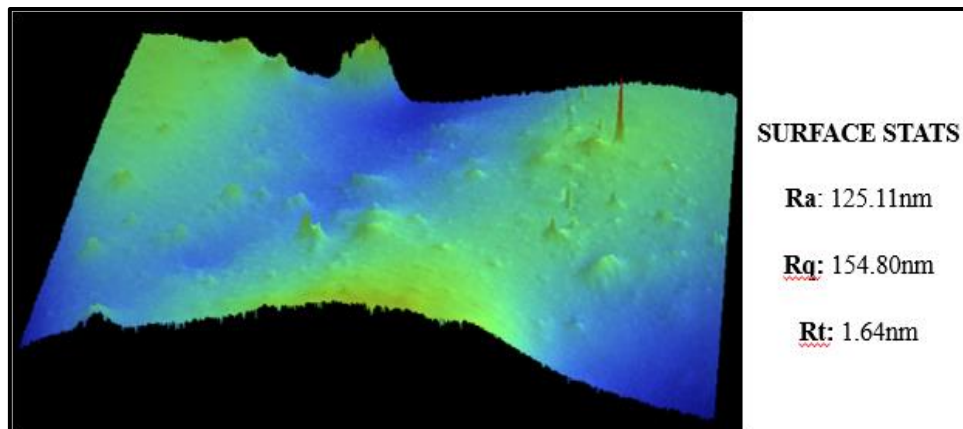


Figure 7a: Clarity Ultra, 3M

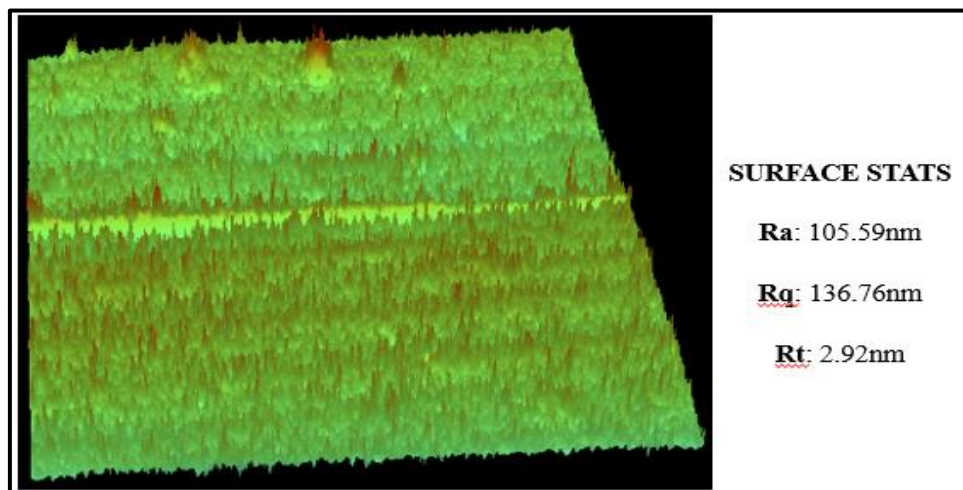


Figure 7b: Empower Clear, AO

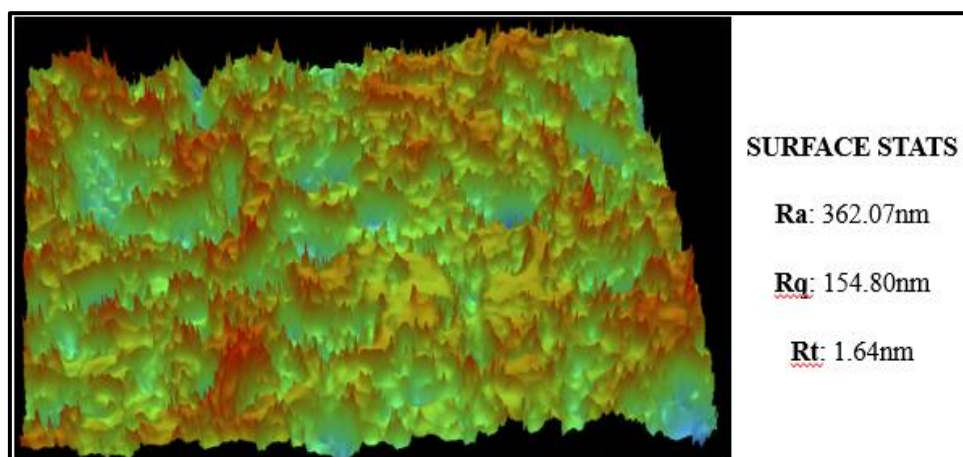
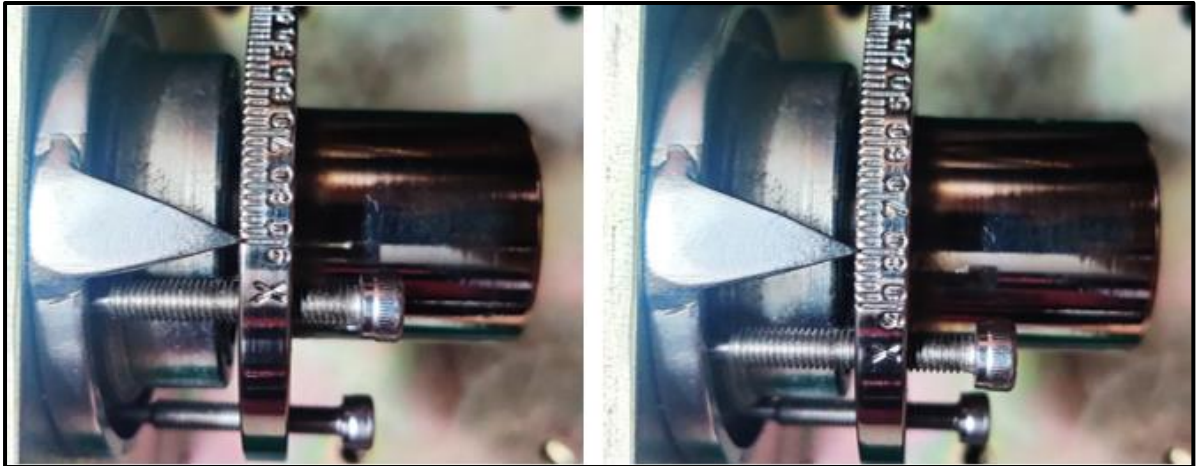


Figure 7c: Victory, 3M

Figure 8: Device Angulation



0° bracket- archwire angulation

10° bracket archwire angulation

Figure 9: Brackets Mounted on the Device



Figure 9a: Clarity Ultra, 3M

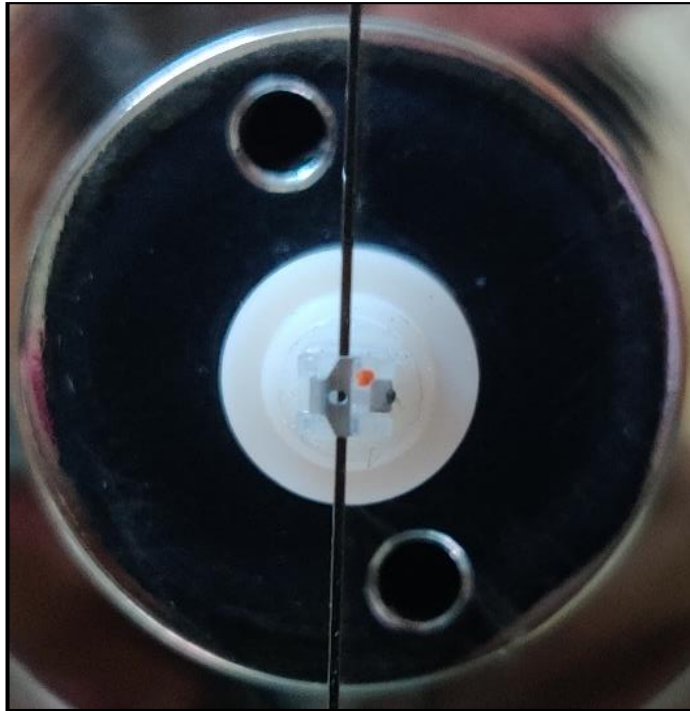


Figure 9b: Empower clear, AO

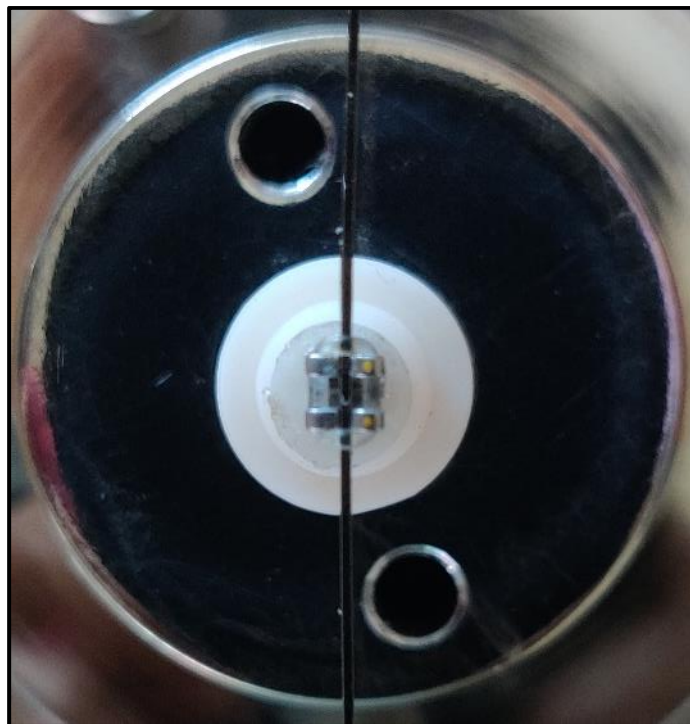
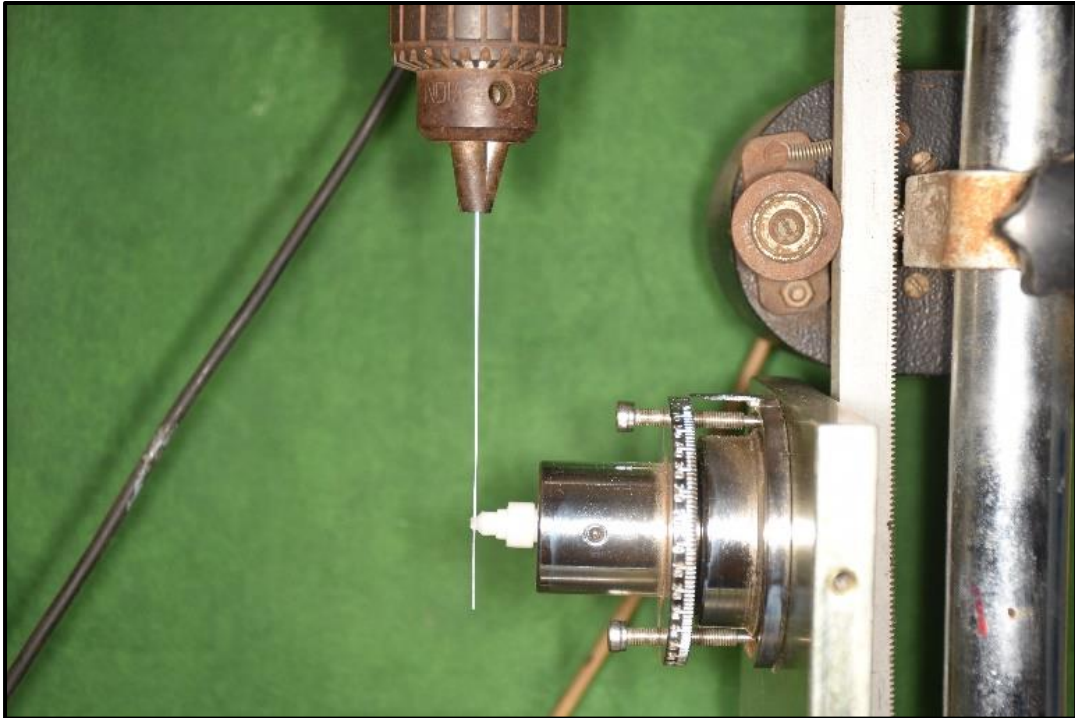


Figure 9c: Victory, 3M

Figure 10: Testing Apparatus



DATA RECORDED

The surface roughness values of the passive ceramic self-ligating bracket, interactive ceramic self-ligating brackets and conventional metal brackets at the midpoint of the slot base was measured and tabulated as given in table 1.

Table 1: Surface Roughness Values of Three Types of Brackets

S.NO	Passive Ceramic Self-Ligating Bracket	Interactive Ceramic Self-Ligating Bracket	Conventional Metal Bracket
1	98.94	134	362.07
2	114.22	73.16	353.53
3	105.5	87.25	384.54
4	147.65	89.97	324.79
5	77.23	72.8	377
6	135.85	100.47	321.25
7	139.21	105.59	426.4
8	127.54	81.36	370.41
9	114.14	96.92	326.43
10	118.83	94.56	347.49
11	105.73	115.71	395.74
12	127.54	114.84	331.66
13	138.81	75.18	376.93
14	114.62	104.18	320.14
15	126.46	99.29	389.95
16	119.94	83.52	421.26
17	91.6	100.33	362.32
18	108.35	85.59	324.35
19	109.07	75.91	372.44
20	125.11	95.23	371.41

The values for resistance to sliding of passive ceramic self-ligating brackets, interactive ceramic self-ligating brackets and conventional metal brackets with elastomeric ligatures were collected and tabulated as given in table 2.

Table 2: Resistance to Sliding at 0° and 10° Bracket- Archwire Angulation

S. No.	Bracket	Wire	Resistance to Sliding (Newton)	
			0° Angle	10° Angle
GROUP 1				
1	Passive ceramic self-ligating bracket	0.018 SS	1.18	1.76
2	Passive ceramic self-ligating bracket	0.018 SS	1.26	1.81
3	Passive ceramic self-ligating bracket	0.018 SS	1.21	1.77
4	Passive ceramic self-ligating bracket	0.018 SS	1.16	1.71
5	Passive ceramic self-ligating bracket	0.018 SS	1.22	1.82
6	Passive ceramic self-ligating bracket	0.018 SS	1.18	1.77
7	Passive ceramic self-ligating bracket	0.018 SS	1.22	1.78
8	Passive ceramic self-ligating bracket	0.018 SS	1.26	1.81
9	Passive ceramic self-ligating bracket	0.018 SS	1.18	1.77
10	Passive ceramic self-ligating bracket	0.018 SS	1.23	1.81

GROUP 2				
1	Passive ceramic self-ligating bracket	0.019 X 0.025 SS	1.77	2.03
2	Passive ceramic self-ligating bracket	0.019 X 0.025 SS	1.74	1.99
3	Passive ceramic self-ligating bracket	0.019 X 0.025 SS	1.78	2.05
4	Passive ceramic self-ligating bracket	0.019 X 0.025 SS	1.65	1.93
5	Passive ceramic self-ligating bracket	0.019 X 0.025 SS	1.77	2.01
6	Passive ceramic self-ligating bracket	0.019 X 0.025 SS	1.68	1.96
7	Passive ceramic self-ligating bracket	0.019 X 0.025 SS	1.76	1.99
8	Passive ceramic self-ligating bracket	0.019 X 0.025 SS	1.72	1.97
9	Passive ceramic self-ligating bracket	0.019 X 0.025 SS	1.73	1.98
10	Passive ceramic self-ligating bracket	0.019 X 0.025 SS	1.69	1.97

GROUP 3				
1	Interactive ceramic self-ligating bracket	0.018 SS	1.16	1.9
2	Interactive ceramic self-ligating bracket	0.018 SS	1.19	1.97
3	Interactive ceramic self-ligating bracket	0.018 SS	1.17	1.91
4	Interactive ceramic self-ligating bracket	0.018 SS	1.15	1.87
5	Interactive ceramic self-ligating bracket	0.018 SS	1.24	2
6	Interactive ceramic self-ligating bracket	0.018 SS	1.21	1.98
7	Interactive ceramic self-ligating bracket	0.018 SS	1.17	1.92

8	Interactive ceramic self-ligating bracket	0.018 SS	1.18	1.92
9	Interactive ceramic self-ligating bracket	0.018 SS	1.2	1.97
10	Interactive ceramic self-ligating bracket	0.018 SS	1.23	2.02

GROUP 4				
1	Interactive ceramic self-ligating bracket	0.019 X 0.025 SS	1.93	3.95
2	Interactive ceramic self-ligating bracket	0.019 X 0.025 SS	1.89	3.82
3	Interactive ceramic self-ligating bracket	0.019 X 0.025 SS	1.76	3.75
4	Interactive ceramic self-ligating bracket	0.019 X 0.025 SS	1.84	3.76
5	Interactive ceramic self-ligating bracket	0.019 X 0.025 SS	1.91	3.86
6	Interactive ceramic self-ligating bracket	0.019 X 0.025 SS	1.76	3.71
7	Interactive ceramic self-ligating bracket	0.019 X 0.025 SS	1.77	3.75
8	Interactive ceramic self-ligating bracket	0.019 X 0.025 SS	1.84	3.76
9	Interactive ceramic self-ligating bracket	0.019 X 0.025 SS	1.9	3.86
10	Interactive ceramic self-ligating bracket	0.019 X 0.025 SS	1.88	3.77

GROUP 5				
1	Conventional metal bracket with elastomeric ligature	0.018 SS	5.5	6.66
2	Conventional metal bracket with elastomeric ligature	0.018 SS	5.56	6.66
3	Conventional metal bracket with elastomeric ligature	0.018 SS	5.6	6.68
4	Conventional metal bracket with elastomeric ligature	0.018 SS	5.58	6.71

5	Conventional metal bracket with elastomeric ligature	0.018 SS	5.66	6.79
6	Conventional metal bracket with elastomeric ligature	0.018 SS	5.5	6.66
7	Conventional metal bracket with elastomeric ligature	0.018 SS	5.6	6.73
8	Conventional metal bracket with elastomeric ligature	0.018 SS	5.65	6.75
9	Conventional metal bracket with elastomeric ligature	0.018 SS	5.45	6.65
10	Conventional metal bracket with elastomeric ligature	0.018 SS	5.61	6.75

GROUP 6				
1	Conventional metal bracket with elastomeric ligature	0.019 X 0.025 SS	6.5	9.04
2	Conventional metal bracket with elastomeric ligature	0.019 X 0.025 SS	6.52	9.07
3	Conventional metal bracket with elastomeric ligature	0.019 X 0.025 SS	6.49	9.01
4	Conventional metal bracket with elastomeric ligature	0.019 X 0.025 SS	6.47	8.99
5	Conventional metal bracket with elastomeric ligature	0.019 X 0.025 SS	6.48	9.06
6	Conventional metal bracket with elastomeric ligature	0.019 X 0.025 SS	6.49	9.01
7	Conventional metal bracket with elastomeric ligature	0.019 X 0.025 SS	6.5	9.03
8	Conventional metal bracket with elastomeric ligature	0.019 X 0.025 SS	6.54	9.08
9	Conventional metal bracket with elastomeric ligature	0.019 X 0.025 SS	6.51	9.02
10	Conventional metal bracket with elastomeric ligature	0.019 X 0.025 SS	6.54	9.08

STATISTICAL ANALYSIS

Data was tabulated in excel sheet and analysed statistically using SPSS software version 24.

The results were statistically tested for normality of distribution and equality of error variance. This was followed by a one way ANOVA for surface roughness and intergroup comparison with post hoc- Games Howell test. For the values of resistance to sliding, a three way ANOVA was done and intergroup comparison was evaluated with a post hoc- Tukey test

RESULTS FOR SURFACE ROUGHNESS

Table 3: Shapiro Wilk's Test of Normality for Surface Roughness

Brackets	Statistic	df	Significance
Passive ceramic self-ligating bracket	0.981	20	0.943
Interactive ceramic self-ligating brackets	0.950	20	0.375
Conventional metal bracket	0.936	20	0.204

The recorded data was assessed for normality using Shapiro Wilk's test of normality and were reported to be distributed normally ($P>0.05$).

Table 4: Levene's Test for Surface Roughness

	Levene Statistic	df1	df2	SIGNIFICANCE
Based on Mean	6.079	2	57	0.004
Based on Median	5.945	2	57	0.005
Based on Median and with adjusted dF	5.945	2	40.635	0.005
Based on trimmed mean	6.128	2	57	0.004

The recorded data was analysed for homogeneity of variance by Levenes test and was reported to be heterogenous in nature ($P < 0.05$).

Table 5: One Way ANOVA for Surface Roughness of the Brackets

Brackets	N	Mean (nm)	Standard Deviation	Significance
Passive ceramic self-ligating brackets	20	117.317	17.202	$P < 0.001$
Interactive ceramic self-ligating brackets	20	94.293	15.943	$P < 0.001$
Conventional metal bracket	20	363.005	32.008	$P < 0.001$

As analysed by one-way ANOVA, the least frictional force was seen in interactive ceramic self-ligating bracket (94.294nm) followed by passive ceramic self-ligating bracket (117.317nm) and the maximum in conventional metal brackets (363.005nm).

Table 6: Post Hoc Games Howell Test for Surface Roughness

Bracket 1	Bracket 2	Mean Difference (nm)	Std. Error	P Value
Passive ceramic self-ligating bracket	Interactive ceramic self-ligating bracket	23.024	5.244	P <0.001
	Conventional metal bracket with elastomeric ligature	-245.688	8.125	P <0.001
Interactive ceramic self-ligating bracket	Passive ceramic self-ligating bracket	-23.024	5.244	P <0.001
	Conventional metal bracket with elastomeric ligature	-268.712	7.995	P <0.001
Conventional metal bracket with elastomeric ligature	Passive ceramic self-ligating bracket	245.688	8.125	P <0.001
	Interactive ceramic self-ligating bracket	268.712	7.995	P <0.001

For multiple comparisons between groups, mean was obtained and statistically significant difference was noted. On comparing passive ceramic self-ligating bracket to interactive ceramic self-ligating bracket, a mean difference of 23.024nm was observed, which denotes increased surface roughness of passive ceramic self-ligating bracket than interactive ceramic self-ligating bracket. Similarly, on comparing passive ceramic self-ligating bracket to conventional metal brackets, a mean difference of -245.688nm was obtained, that denotes increased surface roughness of conventional metal bracket than passive ceramic self-ligating bracket. When comparing interactive ceramic self-ligating bracket to conventional metal brackets, a mean difference of -268.712nm was obtained, that denotes increased surface roughness of conventional metal bracket than interactive ceramic self-ligating bracket.

RESULTS FOR RESISTANCE TO SLIDING

Table 7: Shapiro- Wilks Test of Normality for Resistance to Sliding

Bracket	Wire (Stainless Steel)	Statistic	df	Significance
Passive ceramic self-ligating bracket	0.018	0.921	10	0.363
Passive ceramic self-ligating bracket	0.018	0.851	10	0.06
Passive ceramic self-ligating bracket	0.019 x 0.025	0.904	10	0.24
Passive ceramic self-ligating bracket	0.019 x 0.025	0.974	10	0.923
Interactive ceramic self-ligating bracket	0.018	0.953	10	0.705
Interactive ceramic self-ligating bracket	0.018	0.951	10	0.677
Interactive ceramic self-ligating bracket	0.019 x 0.025	0.882	10	0.137
Interactive ceramic self-ligating bracket	0.019 x 0.025	0.891	10	0.172
Conventional metal bracket with elastomeric ligatures	0.018	0.938	10	0.526
Conventional metal bracket with elastomeric ligatures	0.018	0.893	10	0.183
Conventional metal bracket with elastomeric ligatures	0.019 x 0.025	0.939	10	0.539
Conventional metal bracket with elastomeric ligatures	0.019 x 0.025	0.928	10	0.426

The recorded data was assessed for normality using Shapiro Wilk's test of normality and were reported to be distributed normally as $P > 0.05$.

Table 8: Levene's Test for Resistance to Sliding

	Levene Statistic	df1	df2	Significance
Based on Mean	3.849	11	108	0.000
Based on Median	2.288	11	108	0.015
Based on Median and with adjusted dF	2.288	11	46.724	0.025
Based on trimmed mean	3.676	11	108	0.000

The recorded data was analysed for homogeneity of variance by Levenes test for equality of error variance and was reported to be heterogenous in nature as $P < 0.05$.

A 3 way ANOVA was conducted, as the reading were normally distributed, to determine the effects of resistance to sliding generated between bracket and archwire in different bracket types, wire cross section and bracket- archwire angulations on the frictional values. Data are mean $\pm$ standard deviation.

Table 9: Three way ANOVA for Resistance to Sliding

Source	Type III Sum of Squares	df	Mean Square	F	Significance
Corrected Model	782.78	11	71.16	32927.2	0.000
Intercept	1563.63	1	1563.63	723502.1	0.000
Bracket	676.58	2	338.29	156528.9	0.000
Wire	35.13	1	35.13	16256	0.000
Angle	43.40	1	43.40	20083.36	0.000
Bracket * Wire	8.60	2	4.30	1990.62	0.000
Bracket * angle	10.32	2	5.162	2388.33	0.000
Wire * angle	4.32	1	4.32	1999.16	0.000
Bracket * Wire * angle	4.41	2	2.21	1022.45	0.000
Error	0.23	108	0.00		
Total	2346.65	120			
Corrected Total	783.02	119			

There was statistically significant difference in the one way interaction among bracket types- passive ceramic self-ligating brackets, interactive ceramic self-ligating brackets and conventional metal brackets (control group), wire cross section (round and rectangular wire) and bracket- archwire angulation (0° and 10°) ($P < 0.001$). Similarly, statistically significant difference was noted in the two way interaction between bracket types and wire cross section, bracket types and bracket- archwire angulation, wire cross section and bracket- archwire angulation ($P < 0.001$). Likewise, statistically significant difference was also noted in the three way interaction between bracket types, wire cross section and bracket- archwire angulation ($P < 0.001$).

Table 10: Resistance to Sliding of 0.018" SS Wires

Group	Bracket-Archwire Angulation	Mean (Newton)	Std Deviation	Std Error
Passive ceramic self-ligating bracket (Group 1)	0°	1.21	0.034	0.015
	10°	1.791	0.019	0.015
Interactive ceramic self-ligating bracket (Group 3)	0°	1.19	0.029	0.015
	10°	1.946	0.048	0.015
Conventional metal bracket with elastomeric ligatures (Group 5)	0°	5.571	0.068	0.015
	10°	6.704	0.049	0.015

On comparison between all the three brackets with 0.018" SS wires at 0° bracket- archwire angulation, resistance to sliding was the least in group 3 (interactive ceramic self-ligating brackets) with 1.19N, followed by group 1 (passive ceramic self-ligating brackets) with 1.21N and maximum in group 5 (conventional metal bracket with elastomeric ligatures) with 5.571N, where the values are statistically significant.

Furthermore, at 10 ° bracket- archwire angulation the least resistance to sliding was noted in group 1 (passive ceramic self-ligating brackets) with 1.791N, followed by group 3 (interactive ceramic self-ligating brackets) with 1.946N and maximum in group 5 (conventional metal bracket with elastomeric ligatures) with 6.704N, where the values are statistically significant.

Table 11: Resistance to Sliding of 0.019 X 0.025" SS Wires

Group	Bracket-Archwire Angulation	Mean (Newton)	Std Deviation	Std Error
Passive ceramic self-ligating bracket (Group 2)	0°	1.727	0.041	0.015
	10°	1.988	0.034	0.015
Interactive ceramic self-ligating bracket (Group 4)	0°	1.848	0.064	0.015
	10°	3.799	0.072	0.015
Conventional metal bracket with elastomeric ligatures (Group 6)	0°	6.504	0.023	0.015
	10°	9.039	0.032	0.015

On comparison between all the three brackets with 0.019 X 0.025" SS wires at 0° bracket- archwire angulation, resistance to sliding was the least in group 2 (passive ceramic self-ligating brackets) with 1.727N followed by group 4 (interactive ceramic self-ligating brackets) with 1.848N and maximum in group 6 (conventional metal bracket with elastomeric ligatures) with 6.504N, where the values are statistically significant.

Furthermore, at 10 ° bracket- archwire angulation, the least resistance to sliding was noted in group 2 (passive ceramic self-ligating brackets) with 1.988N followed by group 4 (interactive ceramic self-ligating brackets) with 3.799N and maximum in group 6 (conventional metal bracket with elastomeric ligatures) with 9.039N, where the results are statistically significant.

Table 12: Resistance to Sliding at 0° and 10° Bracket- Archwire Angulation

Groups	Mean At 0° (Newton)		Mean At 10° (Newton)	
	0.018" SS	0.019 X 0.025" SS	0.018" SS	0.019 X 0.025" SS
Passive ceramic self-ligating bracket	1.21	1.727	1.791	1.988
Interactive ceramic self-ligating bracket	1.19	1.848	1.946	3.799
Conventional metal bracket with elastomeric ligatures	5.571	6.504	6.704	9.039

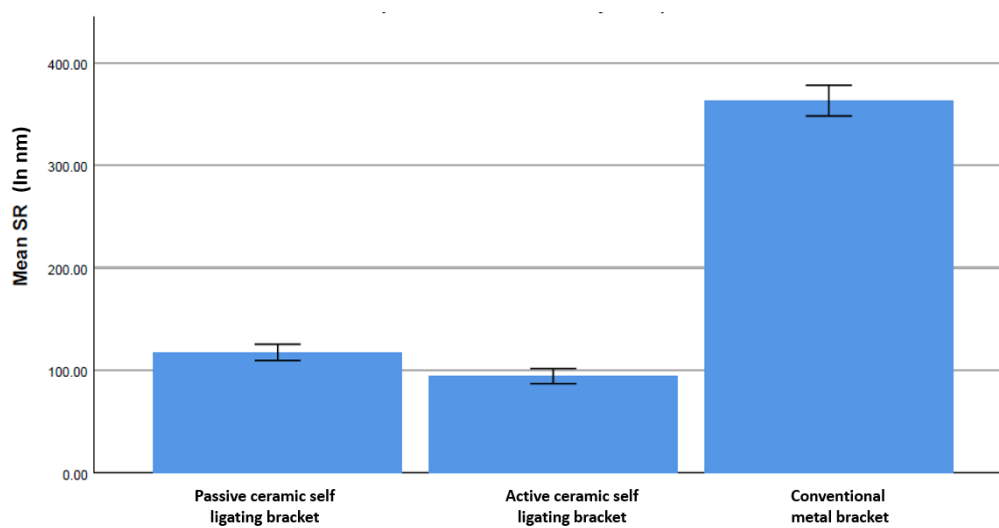
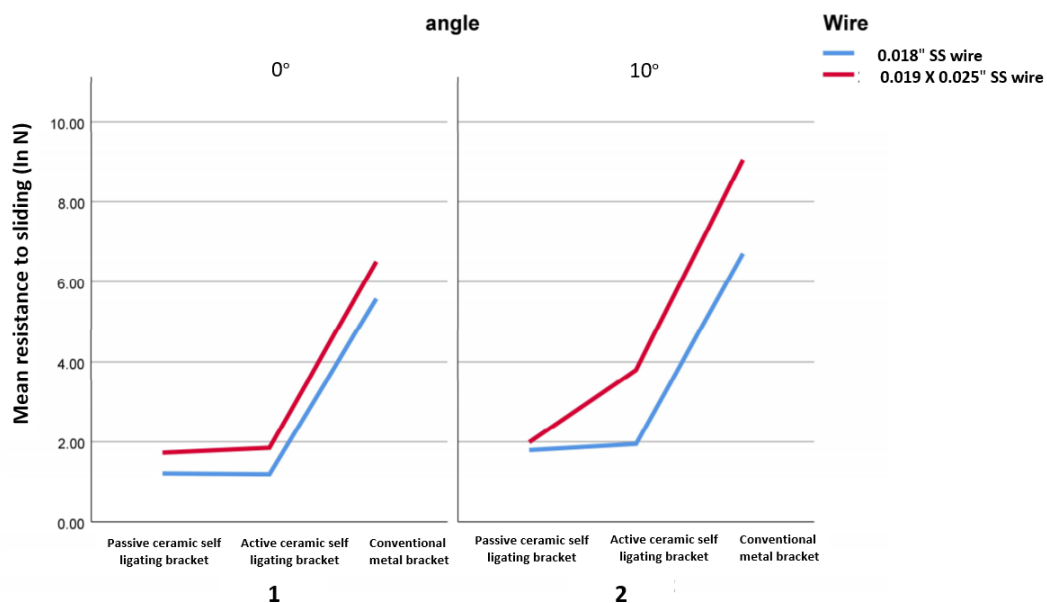
On comparing resistance to sliding values at 0° and 10° angulation with both the wires, friction was larger and statistically significant when the bracket archwire angulation was 10° compared to when the bracket archwire angulation was 0° for all the tested brackets. There was double the increase in values when interactive ceramic self-ligating bracket with 0.019 X 0.025" SS archwire was compared at 0° (1.848N) and 10° (3.799) angulation. Similarly conventional metal bracket with elastomeric ligatures with 0.019 X 0.025" SS archwire also showed a large difference in mean resistance to sliding between 0° (6.504N) and 10° (9.039N).

Table 13: Post Hoc Tukey Test for Resistance to Sliding

Bracket 1	Bracket 2	Mean (Newton)	Std Error	P Value
Passive ceramic self-ligating bracket	Interactive ceramic self-ligating bracket	-0.516	0.01	0.000
	Conventional metal bracket with elastomeric ligatures	-5.275	0.01	0.000
Interactive ceramic self-ligating bracket	Passive ceramic self-ligating bracket	0.516	0.01	0.000
	Conventional metal bracket with elastomeric ligatures	-4.758	0.01	0.000
Conventional metal bracket with elastomeric ligatures	Passive ceramic self-ligating bracket	5.275	0.01	0.000
	Interactive ceramic self-ligating bracket	4.758	0.01	0.000

Pairwise comparison was seen for bracket type with Post Hoc Tukey test for 0.018" and 0.019 X 0.025" SS archwires in 0° and 10° angulation revealed statistically significant differences between all pairs of brackets ($P < 0.001$).

On comparing passive ceramic self-ligating bracket to interactive ceramic self-ligating bracket, a mean difference of -0.516N was observed, which denotes increased resistance to sliding of interactive ceramic self-ligating bracket compared to passive ceramic self-ligating bracket. Similarly, on comparing passive ceramic self-ligating bracket to conventional metal brackets with elastomeric ligature, a mean difference of -5.275N was obtained, that denotes increased resistance to sliding of conventional metal brackets than passive ceramic self-ligating bracket. When comparing interactive ceramic self-ligating bracket to conventional metal brackets, a mean difference of -4.758 was obtained, that denotes increased resistance to sliding of conventional metal brackets than interactive ceramic self-ligating bracket.

Graph 1: Comparison of surface roughness among brackets**Graph 2: Comparison of resistance to sliding among brackets**

DISCUSSION

During orthodontic tooth movement, resistance to sliding (RS) is created at the wire-bracket interface, which significantly influences the character of the force imparted to the teeth. This resistance is believed to reduce the efficiency of orthodontic appliances and consequently a slower tooth movement is observed. The phenomenon of resistance to sliding is observed during levelling/ alignment, retraction and torque expression during treatment⁵⁹. The variables affecting the resistance to sliding during orthodontic treatment can be biological like saliva, plaque, etc and mechanical such as the material of the bracket, slot roughness, slot depth/ height, method of ligation, archwire material, archwire diameter, etc⁶⁰.

It has been documented that stainless steel brackets have the least resistance to sliding compared to ceramic brackets²⁹. Self-ligating ceramic brackets is one of the innovation to meet both the demands of reduced friction and esthetic appearance.

Previous studies showed that there is a direct correlation between the surface roughness of the orthodontic bracket and archwire with the amount of friction exerted⁵⁸. Similarly, wire dimension and angulation also influences resistance to sliding. Larger dimension wires have increased resistance to sliding in comparison to smaller wires⁵⁷. In a study conducted by Articolo et al concluded that greater the angulation of the wire in relation to the bracket slot, an increase in resistance to sliding was observed³⁵.

Studies demonstrating the frictional properties of ceramic self-ligating brackets (SLB) with different archwire diameter and varying angulations are very minimal. Hence, the aim of the present study is to evaluate the surface roughness and resistance to sliding of two commercially available ceramic self-ligating brackets by varying bracket archwire angulation using round and rectangular wires.

To analyze surface roughness and resistance to sliding, Clarity Ultra (3M Unitek) and Empower clear (American Orthodontics) brackets were selected. Clarity Ultra is a passive ceramic SLB and Empower clear is an interactive ceramic SLB that claims to have fine grained surface to reduce resistance to sliding. Conventional stainless steel, Victory (3M Unitek) bracket was also tested and kept as control.

Surface roughness of the bracket slot base was evaluated using a 3D non-contact optical profilometer. It is based on white light interferometry method (He-Ne beam of 633 nm) which determines surface roughness parameters by using 3D imaging. This does not require any sample preparation and is non-destructive. Previous researchers have estimated surface roughness with Scanning Electron Microscope, Atomic Force Microscope and Contact Profilometer. Nevertheless, scanning electron microscope can visualize only a two dimensional surface morphology, and a quantitative information will not be provided. Likewise, atomic force microscopy and contact profilometer damages the surface of

the sample as the scanning requires a moving physical probe touching the surface of the slot base⁵⁵.

The brackets were assessed for resistance to sliding using a Universal Testing Machine (UTM). It is the instrument of choice as it can measure stress and strain with great accuracy, repeatability and also sensitive upto 0.01N. The brackets were bonded to a customised Teflon block, which was attached to a mounting device and the whole set up was transferred to the UTM. Resistance to sliding was tested with two wire dimensions, 0.018" and 0.019 X 0.025" stainless steel (SS) archwires. In a study conducted by Sunda et al, where he evaluated the friction of 0.018" SS archwires, 0.018" Australian wire, and 0.019 X 0.025" SS archwire, he concluded that 0.018" SS archwire is better for canine retraction in the 0.022" slot⁵⁷. Similarly, 0.019 X 0.025" SS archwire is recommended for en masse retraction in 0.022" slot preadjusted edgewise appliance as advocated by Proffit et al⁶¹.

The acquired data were tabulated (table 1 and table 2) and statistically tested for normality of distribution (table 3 and table 7) and equality of error variance (table 4 and table 8). This was followed by a one way ANOVA for surface roughness and intergroup comparison with post hoc- Games Howell test. For the values of resistance to sliding, a three way ANOVA was done and intergroup comparison was evaluated with a post hoc- Tukey test.

The results of our study revealed, among passive ceramic SLB, interactive ceramic SLB and conventional metal brackets, the

interactive ceramic SLB (Empower clear, AO) showed the least surface roughness (94.29nm), followed by passive ceramic SLB (117.31nm) and the maximum in conventional metal brackets (363.005nm). Post hoc Games Howell test (table 6) was done to compare between groups. On comparing passive and interactive ceramic SLB, it has been revealed that passive ceramic SLB showed an increase in surface roughness by 23.02 nm. Likewise, on comparing passive ceramic SLB and conventional metal brackets, it has been revealed that conventional metal brackets showed an increase in surface roughness by 245.68 nm. Finally, on comparing interactive ceramic SLB and conventional metal brackets, it has been revealed that conventional metal brackets showed an increase in surface roughness by 268.71nm. Our results were in accordance with the study conducted by Lee and Park, where they stated that the surface roughness of ceramic SLB was lesser when compared to metal SLB and conventional ceramic SLB⁶². In another study by Lee and Hwang, who stated that active ceramic SLB had lesser surface roughness than active metal SLB, and claims it could be due to the surface treatment in the slot area of the ceramic SLB¹.

In this study, resistance to sliding was tested with Universal Testing Machine under dry conditions since the effect of lubrication by saliva on friction is controversial. Baker et al found that artificial saliva acted as a lubricant bringing about 15 to 19% reduction in frictional force values generated between stainless steel brackets and archwire²⁷. Conversely, Andreasen and Quevedo et al

claimed that saliva played an insignificant role in lubricating the surface of the archwire in the bracket slot. The explanation they gave for this finding was that the archwire touches the bracket at only two points, where the pressure is relatively great. The lubricant could be expelled from the area of contact, allowing no lubrication between the archwire and brackets to exist²⁵. Moreover, Kusy et al regarded artificial saliva as inadequate replacement for human saliva and declared such experiments as invalid²². Hence, dry condition was considered ideal for this study.

A crosshead speed of 5 mm/min was selected according to Tidy et al. He believed that for experimentation higher speeds should not be considered as it did not represent the clinical situation²⁸.

When analysing the resistance to sliding of 0.018" stainless steel wires at 0° bracket- archwire angulation (Table 10), the least values were noted in interactive ceramic SLB (1.19N), followed by passive ceramic SLB (1.21N). Conventional metal bracket with elastomeric ligatures exhibited the maximum resistance to sliding (5.571N). The values of resistance to sliding was the least for interactive ceramic brackets than passive ceramic brackets at 0° angulation because the interactive brackets behaves similar to passive brackets at smaller wire dimensions. Smaller wires show a lack of contact with slot walls or spring clips that leads to a reduction in the resistance to motion. The reduced resistance to sliding of interactive ceramic SLB could also be based on the fact

that the interactive ceramic SLB revealed significantly lower surface roughness on the slot base than the passive ceramic SLB. This result was in accordance with the study by Brauchli et al, where he demonstrated that low friction can be achieved in passive SLB as well as active SLB in combination with smaller dimension archwires. He concluded that when a small size archwire was used, there was no significant difference in friction between active and passive SLB⁴⁶. Similar results were reported by Vale et al, where no statistically significant differences in resistance to sliding were observed between passive and active types⁵⁴.

When evaluating the resistance to sliding of 0.018" stainless steel wires at 10° bracket- archwire angulation (Table 10), the least resistance to sliding was noted in passive ceramic SLB (1.79N), followed by interactive ceramic SLB (1.94N) and the maximum in conventional metal bracket with elastomeric ligatures (6.70N).

When estimating the resistance to sliding of 0.019 X 0.025" stainless steel at 0° bracket- archwire angulation (Table 11), the least values were observed in passive ceramic SLB (1.72N), followed by interactive ceramic SLB (1.84N) and the maximum in conventional metal bracket with elastomeric ligatures (6.50N).

When examining the resistance to sliding of 0.019 X 0.025" stainless steel at 10° bracket- archwire angulation (Table 11), the least resistance to sliding was noted in passive ceramic SLB (1.98N), followed by interactive ceramic SLB (3.79N) and the maximum in conventional metal bracket with elastomeric ligatures

(9.03N). The above values showed that 0.019 X 0.025" stainless steel rectangular wire showed increased values for resistance to sliding than 0.018" stainless steel wire in ceramic SLB and conventional metal brackets. Our results were similar to study by Lee et al and Tecco et al, where frictional resistance was higher with rectangular wire than with round wire in all experimental groups, including all types of bracket materials, wire material and different angulation^{1,39}.

On comparing the resistance to sliding at 0° and 10° bracket-archwire angulation (Table 12), resistance to sliding was the least in passive ceramic SLB (except in 0.018" SS at 0°) followed by interactive ceramic SLB and the maximum in conventional metal brackets.

On pairwise comparison between bracket types (post hoc Tukey test- table 13), passive ceramic SLB was lesser than interactive SLB by a mean of 0.51N and lesser than conventional metal bracket with elastomeric ligatures by 5.27N. On comparing interactive ceramic SLB to conventional metal SLB, interactive ceramic SLB was lesser than conventional metal bracket by 4.75N. The least value for passive ceramic SLB was observed, which was expected due to the larger contact angle in passive ceramic SLB, compared to interactive ceramic SLB and the conventional metal brackets. In a similar study by Williams et al, self-ligating ceramic brackets generated significantly lower frictional force (2.92 N) than conventional metal brackets (3.63 N) when 0.018 X 0.025" stainless

steel wire was engaged⁴⁹. The ligation force produced by conventional brackets caused the wire to be in contact with lateral walls of the slot, thus yielding binary forces that increase the friction. This could be the reason for increased resistance to sliding in conventional metal brackets.

It has been noticed that the interactive ceramic brackets with 0.019 X 0.025" stainless steel wire showed an increase in resistance to sliding by two fold as the angulation increased from 0° (1.84N) to 10° (3.79N). Similarly conventional metal bracket with elastomeric ligatures engaged with 0.019 X 0.025" stainless steel archwire also showed a large difference in mean resistance to sliding between 0° (6.5N) and 10° (9.03N). This proves that the rate of increase in resistance to sliding with respect to increase in angulation is higher with rectangular wires than with round wires. Resistance to sliding for passive ceramic SLB when the angulation increased was lesser than the interactive ceramic SLB and conventional metal brackets. This could be due to the increased slot size in passive SLB, which in turn increased the contact angle and reduced the effect of binding.

Frank and Nikolai reported that the rate of increase in frictional resistance was greater when the angle increased from 5° to 10° than when the angle increased from 0° to 5°²⁶. Additionally, Pizzoni et al reported that self-ligating brackets had low sliding forces at 0° and 3°, which increased proportionally with an increase in the angle to 6°, 9°, and 12°. This could be because the sliding

movement of teeth can be disturbed by vertical forces produced at both ends of the bracket slot as the bracket-archwire angulation increased causing binding²³.

In our study, the resistance to sliding was evaluated with a single bracket which may not simulate the clinical situation. In the future studies, a model resembling a segment of the arch with ideal interbracket distance can be considered. In the same way, the present study being in vitro, showed difficulty in extrapolating the values of friction determined compared to an in vivo situation. This was because reproducing oral conditions like muscular forces, occlusal forces, and moving tooth through bone is arduous. Moreover, only two types of ceramic SLB and its interaction with wires of 0.018" and 0.019 X 0.025" stainless steel archwires were evaluated in this study. Hence future studies are recommended mimicking in vivo situation with different brackets, archwire dimension and materials.

SUMMARY AND CONCLUSION

In this study, surface roughness and resistance to sliding of two commercially available ceramic self-ligating brackets (Empower clear and Clarity Ultra) was evaluated by varying bracket archwire angulation (0° and 10°) using round (0.018" stainless steel) and rectangular (0.019 X 0.025" stainless steel) wires. Conventional metal bracket (Victory) with elastomeric ligatures were kept as control. Surface roughness was measured using a 3D non-contact optical profilometer and resistance to sliding was checked with a Universal Testing machine.

The following conclusions were drawn from the results of the study:

- Surface roughness was the least in interactive ceramic SLB (Empower clear), followed by passive ceramic SLB (3M Clarity Ultra) and the maximum in conventional metal brackets (3M Victory) and the results were statistically significant.
- The direct correlation between surface roughness and resistance to sliding exist only upto the range where the wire allows the interactive bracket to behave passively (such as, in 0.018" SS at 0° angulation)
- Resistance to sliding was the least in passive ceramic SLB (except in 0.018" SS) followed by interactive ceramic SLB and the maximum resistance to sliding was observed in

conventional metal brackets in both 0° and 10° angulation. The results were statistically significant.

- Round wire (0.018" SS) showed the least resistance to sliding than the rectangular wire (0.019 X 0.025" SS) in all bracket types and angulations.
- Resistance to sliding significantly increased when the bracket-archwire angulation was changed from 0° to 10°. The rate of increase was higher with rectangular wire than with round wire.

Hence, the null hypothesis has been rejected as there is significant difference in the surface roughness and resistance to sliding among the selected ceramic self-ligating brackets and conventional metal brackets.

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