EVALUATION OF FRICTIONAL CHARACTERISTICS OF FOUR COMMERCIALLY AVAILABLE SELF-LIGATING BRACKETS

-AN IN-VITRO STUDY

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CERTIFICATE

This is to certify that this dissertation titled **'EVALUATION OF FRICTIONAL CHARACTERISTICS OF FOUR COMMERCIALLY AVAILABLE SELF-LIGATING BRACKETS -AN IN-VITRO STUDY'** is a bonafide record of work done by **Dr. SUBU THOMAS under** my guidance during his postgraduate study period between2008–2011.

This dissertation is submitted to **THE TAMIL NADU Dr. M.G.R. MEDICAL UNIVERSITY**, in partial fulfillment for the degree of Master **of Dental Surgery** in Branch V –Orthodontics and Dentofacial Orthopedics.

It has not been submitted (partially or fully) for the award of any other degree or diploma.

Guided By

K.M. Shahul H. Faizee

Dr. Shahul Hameed Faizee M.D.S,
Associate Professor& Guide,
Department of Orthodontics and
Dentofacial Orthopaedics,
Ragas Dental College and Hospital,
Chennai.

Head of the Department

N.R.
30/12/10

Dr.N.R.Krishnaswamy M.D.S.,
M.OrthoR.C.S.(Edin), Dip.N.B.(Ortho)
Diplomate of Indian Board of Orthodontics,
Professor and Head,
Department of Orthodontics and Dentofacial
Orthopaedics,
Ragas Dental College & Hospital,
Chennai.

PROFESSOR & HEAD
Dept. of Orthodontics
RAGAS DENTAL COLLEGE & HOSPITAL
2/102, East Coast Road
Uthandi, Chennai-600 119

Principal

Dr. S. Ramachandran, M.D.S.,
Ragas Dental College &Hospital,
Chennai.

PRINCIPAL
RAGAS DENTAL COLLEGE AND HOSPITAL
UTHANDI, CHENNAI-600 119

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CONTENTS

INTRODUCTION

Orthodontic treatment aims to relocate malpositioned teeth within the jaws using application of mechanical forces. Although little is known about the optimal orthodontic force, it is widely assumed that the optimal orthodontic tooth movement occurs under a small and continuous force.[68] During the evolution of the various fully programmed appliances, concomitant improvements and refinements in retraction mechanics resulted in a relatively new procedure called “sliding mechanics”. In orthodontics, the term sliding mechanics implies that there is relative movement between archwire and brackets or tubes.[54] The advantages of sliding mechanics include less complicated wire bending, decreased chair side time and patient comfort, whereas the disadvantage of sliding mechanics is friction and thus slower rate of tooth movement.[54]

Friction is the resistance to motion encountered when one solid body slides or tends to slide over another. It may be described as a force acting parallel and opposite to the direction of this motion.[7] Friction is considered to be significant in decreasing the effective orthodontic force available to move teeth thus reducing the efficiency and rate of tooth movement.[8]

In orthodontics, many studies have used experimental testing models to evaluate the factors that influence frictional resistance between the brackets and the archwire.[2,4,5] These studies showed that the important factors which determine the frictional levels were bracket, bracket slot, torque at the wire-bracket interface, wire materials, surface conditions of archwires, wire section, type and force of ligation, interbracket distance, saliva and influence of oral functions. Consequently, to achieve the desired results the orthodontist needs to apply more force to overcome friction, but light forces are more favorable to initiate and maintain tooth movement because they can result in less painful treatment and help maintain the position of anchorage teeth. [31,45,59,92] So it is the responsibility of the orthodontist to eliminate or minimize the frictional forces whenever orthodontic tooth movement is being planned.

To reduce the incidence of friction during sliding mechanics, many improvements have been made to enhance the treatment outcome.[58] Technical advances in orthodontics offered possible improvements in wires and brackets. The primary motive for introducing the Self-ligating brackets was to quicken the process of archwire removal and placement but the manufacturers claim that one of its main advantage is reduced friction thereby leading to low force values which accelerate tooth movement.

Self-ligating brackets introduced by **Dr. Jacob Stolzenberg 1935** [34] are ligature-less bracket systems that have a mechanical device built into the bracket to close off the edgewise slot. They are generally smoother for the patients because of the absence of wire ligature and also do not require as much chair time.[6,26,52] The precision arm or the sliding fourth wall accurately locks the archwire within the dimensions of the slot providing robust ligation and controlled tooth movement.

The advantages of self-ligating systems over conventional appliances which are claimed to include:

1) **Decrease in treatment duration**--Reduced friction, more robust ligation, more efficient tooth movement in sliding mechanics, and enhanced rotational control.[23,30] It was reported in retrospective analyses that these factors can reduce overall treatment time.[19,43,76]

2) **Anchorage Conservation-** The low friction of these interactive brackets allows the application of consistent, light forces for efficient flow mechanics during retraction. This in turn reduces posterior anchorage loss.[58]

3) **Asepsis**- The four tie-wing undercuts are left open for the self-cleansing effects of salivary fluids. Eliminating the use of conventional elastomeric modules can reduce plaque accumulation contributing to prevention of gingival inflammation and enamel demineralization.[22]

4) **Comfortable for the patient**- In **1990,** Rolf Maijer and smith [52] found that patients bonded with self-ligating brackets invariably reported that the brackets were smoother and wings did not seem to stick into the cheeks and lips, which reduces the risk of skin perforation and possible infection.[15,73]

Self-ligating brackets are broadly classified into Active and Passive self-ligating brackets;

Active self-ligating brackets: Active brackets, with the labial fourth wall consist of a spring clip in contact with the arch wire. Automatic seating of either a round or a rectangular archwire at the base of the slot is responsible for the light, continuous force.[25] These brackets express greater torque control.[3] In the active self-ligating system, friction is produced as a result of the clip pressing against the archwire.[44]

Passive self-ligating brackets: In passive self-ligating brackets, the slot is transformed into a tube by means of a labial "fourth wall" that does not contact the archwire.[15] The full expression of bracket properties is achieved only when higher dimensional wires are used and the rotation control is efficiently achieved only by using larger rectangular archwires.[50, 53]

Self-ligation seems to be gaining more and more popularity in contemporary orthodontics. Compared with conventional appliances, all the commercially available self-ligating mechanisms attribute their increased efficiency and reduced treatment time to their improved frictional characteristics.[13,44] However, considerable variation exists between commercially available bracket types in terms of their mechanical, geometrical, and material-related specifications and this would be expected to affect their frictional performance. For these reasons it was considered important to test the kinetic frictional behavior of self-ligating brackets and compare that to pre adjusted twin brackets with conventional ligation.

Therefore the aim of the present study was to compare the kinetic frictional resistance of four commercially available self-ligating brackets and a preadjusted twin bracket conventionally ligated with elastomeric modules in-vitro with various dimension stainless steel archwire combinations under conditions that would allow replication (from a mechanical standpoint) of the clinical situation.

REVIEW OF LITERATURE

Friction had been mentioned in the orthodontic literature as far back as 1960 when **Stoner**[81] stated “Recognition must always be given the fact, sometimes applied force is dissipated by friction and it is difficult to control and determine the amount of force that is being received by the individual tooth”.

Numerous studies had been undertaken to assess the role ofkinetic friction in sliding mechanics which clearly concludedthat several factors were involved in the contribution of frictional forces. These factors could be either physical or biological in nature. The following are some of the important variables that could affect the frictional forces during sliding mechanics.[58]

1. Bracket
    a. material
    b. manufacturing process
    c. slot width and depth
    d. bracket design
    e. first,second and third order bends
2. Archwire
    a. material
    b. cross-sectional shape/size
    c. surface texture
    d. stiffness

3. Ligation of Bracket to the archwire
    a. ligature wires
    b. elastomeric modules
    c. method of ligation

Considering the above factors the review of literature for this study is categorized into three groups such as brackets, archwires and the method of ligation in relation to friction.

Brackets: -slot size, material and frictional resistance:-

Andreasen et al (1970)[93] conducted studies that compared the frictional resistance of different bracket size slots and widths to variations in archwire size and they reported that frictional force is independent of bracket width.

Frank et al (1980)[10] concluded that with edgewise bracket; friction might be minimized by maximizing the contact area of the wire within the bracket slot, maximizing the bending stiffness and minimizing the bracket width. He suggested a heavy rectangular wire with a narrow slot should be used for canine retraction in edgewise mechanics.

Herbert Hanson (1986)[17] considered SPEED self-ligating brackets to be cosmetic, more hygienic and comfortable for the patient. Furthermore he found that it is easier to visually assess the position and orientation of the archwire slots of the miniature version. He attributes this partly to the fact that less surface of the tooth is obscured by the bracket.

Berger et al(1990)[6] evaluated the force levels of tooth movements in SPEED self-ligating brackets and they demonstrated significant decrease in force level required for the SPEED bracket with all four archwires tested when compared with elastomeric and steel tie ligation in both metal and plastic bracket systems.

Kemp et al(1992)[42] compared the frictional forces between self-ligating and conventional edgewise brackets with different archwire size, archwire alloy or second order angulations. A testing apparatus was constructed to stimulate the clinical situation in which a maxillary canine is retracted through a first pre-molar extraction space along a continuous archwire, with sliding mechanics. The results demonstrated that at 0* and 10* angulation, self-ligating brackets demonstrated lower levels of friction. Round archwires in smaller sizes produced smaller friction.

Shivapuja et al(1994)[73] in their comparative study on the effect of self-ligating bracket and brackets with conventional ligation system observed that self-ligating bracket systems displayed a significantly lower level of frictional resistance,less chair side time and improved infection control compared to metal or ceramic brackets.

Hamula et al (1996)[27] evaluated the properties of titanium brackets and compared them with that of stainless steel brackets and they reported about 30% reduction in friction in titanium brackets when compared to stainless steel brackets. They reported that the formation of thin layer of titanium oxide prevented direct contact between the metallic atoms on the surfaces of the wire and bracket hence reducing inter atomic adhesion and friction and this being the reason for the reduced friction in titanium brackets.

G E Read Ward et al (1997)[23] compared the static frictional resistance of three self-ligating brackets with a conventional steel ligated Ultra–trim bracket. The effects of archwire size, bracket- archwire angulation and the presence of unstimulated human saliva were investigated. The study demonstrated that both increase in wire size and bracket-arch wire angulation resulted in increased static frictional resistance for all bracket types tested, but self -ligating brackets showed reduced frictional resistance in comparison to steel ligated brackets only under certain conditions.

Voudouris (1997)[91] reviewed three types of interactive twin brackets with conventional twin brackets. The interactive twin brackets exhibited low frictional resistance due to the arm engagement with a lower co-efficient of friction and a reduced seating force against the archwire. He reported that interactive twin brackets were hybrids of both conventional twins and interactive single brackets with significant improvements of both the previous systems.

Dwight H Damon (1998)[14] compared the friction produced by three types of conventional twin brackets with three self-ligating brackets. When

0.019x0.025 stainless steel wires were drawn through the bracket, a Conventional twin ligated with elastic modules produced 388 to 609 times the friction of passive self -ligating brackets. Conventional twins with metal ligatures were found to have friction values, more than 300 times those of passive self-ligating brackets. The active self-ligating bracket produced 216 times the friction of a passive self-ligating bracket.

Luca Pizzoni et al (1998)[50] studied the frictional resistance encountered in two self- ligating (Speed, Damon SL) and two conventional brackets (Dentauram). These brackets were tested with four wires (Stainless steel, Beta-titanium - round and rectangular). The result showed that round wires had a lower friction than rectangular wires. Beta-titanium wires had higher friction than stainless steel. The self -ligating brackets had a markedly lower friction than conventional brackets at all angulations. It was concluded that the selection of bracket design, wire material and wire - cross section significantly influences the forces acting in a continuous arch system.

Kapur et al (1998)[40] conducted a study to compare the kinetic frictional force of a new self-ligating bracket (Damon SL) with that of a conventional twin bracket. The results revealed that the self-ligating brackets had lower kinetic coefficient of friction. They concluded that self-ligating brackets could offer a substantial clinical advantage to orthodontists employing sliding mechanics.

Susan Thomas et al (1998)[86] investigated the frictional characteristics of two types of self-ligating brackets - Damon SL(A-company) and Time(Adenta) brackets and two types of pre-adjusted edgewise brackets - Tip-Edge(TP-orthodontics) and Standard Twin(A-company) brackets. Five combinations of arch wire size and material were used -0.014 NiTi, 0.0175 multi-stranded stainless steel, 0.016x0.022 NiTi, 0.016x0.022 stainless steel, and 0.019x0.025 stainless steel wires. Results indicated that the self-ligating brackets produced less frictional resistance than elastomerically tied pre-adjusted edgewise brackets.

Thorstenson et al(2001)[24] compared the frictional properties of conventional stainless steel brackets that were coupled with rectangular stainless steel archwires and closed self-ligating brackets coupled with the same archwires in terms of second order-angulation. They concluded that at all stages; the resistance to sliding of the closed self-ligating brackets was lower than those of the conventional brackets because of the absence of a ligation force.

Thorstenson et al (2002)[25] investigated the resistance to sliding for 3 self-ligating brackets having passive slides and 3 self-ligating brackets having active clips. (Damon, SPEED, Twinlock, In-ovation, Time, Activa). For each bracket, the resistances to sliding were measured at 14 second order angulations, which ranged from -90 to +90. The results showed that at second order angulations, 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. Brackets with passive slides that had a high critical angle exhibited the lowest resistance to sliding, but could also do so at the cost of loss of some control.

Edward Mah (2003)[21] conducted frictional study with self-ligating brackets (In-ovation, and Damon 2), and conventional brackets (Mini-twin, Transcend 6000).These 4 brackets were evaluated with 6 different archwires (0.018 NiTi, 0.018 stainless steel, 0.019x0.025 TMA, 0.018x0.025 stainless steel, 0.019x0.025 stainless steel, and 0.021x0.025 stainless steel). Results showed significant differences in dynamics friction among the different bracket types. The Damon 2 brackets produced significantly lesser dynamic friction compared with the In-ovation brackets. In general, the self-ligating brackets produced significantly lesser static, kinetic and dynamic friction than did conventional brackets, and larger diameter archwires produced greater amount of dynamic friction.

Harradine (2003)[28] explored the treatment efficiency of available self-ligating brackets and concluded that the currently available self-ligating brackets offered the very valuable combination of extremely low friction and secure full bracket engagement and at last, they delivered most of the potential advantages claimed by these type of brackets. These developments offered the possibility of a significant reduction in average treatment time and also in anchorage requirements, particularly in cases requiring large tooth movements.

Darryl V Smith et al (2003)[16] studied the frictional resistance of various bracket archwire combinations. It was concluded that 1) ceramic brackets with and without metal slot had the greatest friction followed by metallic brackets, active self-ligating brackets, variable self-ligating brackets, and passive self-ligating brackets. 2) Stainless steel and braided stainless steel archwires measured greater friction than nickel- titanium. 3) smaller dimension wires had less friction than larger wires, and round wires had less friction than rectangular wires. In addition, consideration of specific bracket -archwire coupling appear to reduce the frictional resistance with sliding.

Henao SP, Kusy Robert et al (2005)[30] studied the frictional behavior of four conventional and four self-ligating brackets that were simulated using a mechanical testing machine. Analyses of the two bracket types were completed by drawing samples of three standardized arch wires through quadrants of typodont models in the dry and wet states. As nominal dimension of the arch wire increased, the drawing forces of all brackets increased at different rates. When coupled with a small wire the self-ligating brackets performed better than the conventional brackets. When coupled with larger wires, various designs interchangeably displayed superior performance.

Simona tecco et al (2005)[75] performed an in-vitro study using a specially designed apparatus that included 10 aligned brackets to compare thefrictional resistance generated by conventional stainless steel brackets, self-ligating Damon SL II brackets and Time Plus brackets coupled with stainless steel, nickel-titanium and beta-titaniumarchwires. All brackets had a 0.022-inch slot, and five different sizes of orthodontic wire alloysused. Each bracket-archwire combination was tested 10 times, and each test was performed with a new bracket-wire sample. Results showed -Time Plus self-ligating brackets generated significantly lower frictionthan both the Damon SL II self-ligating brackets and Victory brackets. However, the analysis ofthe various bracket-archwire combinations showed that Damon SL II brackets generated significantlylower friction than the other brackets when tested with round wires and significantly higherfriction than Time Plus when tested with rectangular archwires. Beta-titanium archwires generated higher frictional resistances than the other archwires. All brackets showed higher frictional forces as the wire size increased. Also these findings suggest that the use of an in vitro testing model that includes 10 brackets can give additional interesting information about the frictional force of the various bracket-archwires combinations to the clinician and the research worker.

Chin-Liang Yeh et al (2007)[12] evaluated the frictional resistance of brackets with passive ligation and compared these values with corresponding controls. Two passive self-ligating brackets (Damon SL II, Sybron Dental Specialties/Ormco, Orange, Calif& SmartClip, 3M Unitek, Monrovia, Calif) and 1 novel bracket with passive elastic ligation (Synergy, Rocky Mountain Orthodontics, Denver) were used. They concluded that the low frictional resistance produced by passive self-ligating brackets can be helpful during orthodontic sliding mechanics.

Nikolaos Pandis (2007)[60] investigated the duration of mandibular crowding alleviation with self-ligating brackets compared with conventional appliances and the accompanying dental effects. The self-ligating group showed a statistically greater intermolar width increase than the conventional group. Also, an alignment-induced increase in the proclination of the mandibular incisors was observed for both bracket groups, but no difference was found between Damon 2 and conventional brackets for this parameter.

Simona Tecco et al (2007)[74] evaluated the frictional resistance generated by conventional stainless steel (SS) brackets (Victory Series), self-ligating Damon SL II brackets, Time Plus brackets, and low-friction ligatures (Slide) coupled with various SS, nickel-titanium (NiTi), and beta-titanium (TMA) archwires. All brackets had a 0.022-inch slot and the orthodontic wire alloys were 0.016, 0.016 × 0.022, and 0.019 × 0.025 inch NiTi, 0.017 × 0.025 inch TMA, and 0.019 × 0.025 inch SS. The Damon SL II brackets showed significantly lower friction compared with all other groups, while Victory Series brackets showed significantly higher friction.

Tae-Kyung Kim(2008)[82] did an in-vitro study to measure the frictional force (FF) generated by various combinations of self-ligating bracket (SLB) types, archwire sizes, alloy types, and the amount of displacement during the initial leveling phase of orthodontic treatment, by using a custom-designed typodontsystem. Methods: Two passive SLBs (Damon 2 [D2] and Damon 3 [D3]), and active SLBs (SPEED [SP], In-Ovation R [IO], Time 2 [T2], and SmartClip) were tested with 0.014-in and 0.016-in austenitic nickel-titanium (A-Ni-Ti) and copper-nickel-titanium (Cu-Ni-Ti) archwires. To simulate malocclusion status, the maxillary canines (MXCs) were displaced vertically, and the mandibular lateral incisors (MNLIs) horizontally from their ideal positions up to 3 mm with 1-mm intervals. Two conventional brackets (Mini-Diamond [MD] and Clarity [CL]) were used as controls.Results showed that frictional forces were increased in the ascending order:D2, D3, IO, T2, SM, SP, CL, and MD in the maxillary typodont; and IO, D2, D3, T2, SP, CL, and MD in the mandibular typodont, regardless of archwire size and alloy type. The A-Ni-Ti wire showed significantly lower friction than the Cu-Ni-Ti wire of the same size. As the amount of vertical displacement of the maxillary canine increased and the horizontal displacement of the mandibular lateral incisor were increased, friction also increased. They concluded that combinations of the passive SLB and A-Ni-Ti archwire during the initial leveling stage can produce lower FF than other combinations of SLB and archwire in vitro.

Steven budd et al (2008)[80] did an investigation to assess and compare the in vitro tribological behaviour of four commercially available self-ligating bracket systems. The frictional characteristics of the Damon3, Speed, In-Ovation R, and Time2 bracket systems were studied using a jig that mimics the three-dimensional movements that occur during sliding mechanics. Each bracket system was tested on the following stainless steel archwires: 0.016 x 0.022, 0.019 x 0.025, 0.020 round, and 0.021 x 0.021 inch Speed D-wire. An Instron testing machine with a 50 N load cell was used to measure the frictional resistance for each bracket/tooth assembly. The crosshead speed was set at a constant rate of 1 mm/minute, and each typodont tooth was moved along a fixed wire segment for a distance of 8 mm. The Damon3 bracket consistently demonstrated the lowest frictional resistance to sliding, while the Speed bracket produced significantly ($P < 0.001$) more frictional resistance than the other brackets tested for any given archwire. The self-ligation design (passive versus active) appears to be the primary variable responsible for the frictional resistance generated by self-ligating brackets during translation. Passively ligated brackets produce less frictional resistance; however, this decreased friction may result in decreased control compared with actively ligated systems.

Sayeh Ehsani, Marie-Alice Mandich (2009)[72] compared the amount of expressed frictional resistance between orthodontic self-ligating brackets and conventionally ligated brackets in vitro as reported in the orthodontic literature. It was found that, compared with conventional brackets, self-ligating brackets produce lower friction when coupled with small round archwires in the absence of tipping and/or torque in an ideally aligned arch. Sufficient evidence was not found to claim that with large rectangular wires, in the presence of tipping and/or torque and in arches with considerable malocclusion, self-ligating brackets produce lower friction compared with conventional brackets.

Lorenzo Franchi, Tiziano Baccetti (2009)[49] analyzed the forces released by 4 types of passive stainless steel self-ligating brackets and 2 non-conventional elastomeric ligature bracket systems compared with conventional elastomeric ligatures on stainless steel brackets during the alignment of buccally displaced teeth. A model consisting of 5 brackets (from second premolar through central incisor) was used to assess the forces released by the bracket-ligature systems with 0.012- or 0.014-in superelastic wires with various samounts of buccal canine displacement (1.5-6.0 mm). They concluded that the non-conventional elastomeric ligature bracket systems produced force levels for tooth movement that were similar to those generated by passive self-ligating brackets.

M. Krishnan et al (2009)[44] conducted an in-vitro study in which they compared the effects of stainless steel, nickel-titanium, and beta-titanium archwires on frictional forces of passive and active self-ligating bracket swith a conventional bracket. All brackets had 0.022-in slots, and the wires were

0.019 x 0.025 in. Friction was evaluated in a simulated half-arch fixed appliance on a Universal testing machine. Results showed that Static and kinetic frictional forces were lower for both the passive and active designs than for the conventional brackets. Maximum values were seen with the beta-titanium archwires, and significant differences were observed between nickel titanium and stainless steel archwires. 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 wires. They concluded that when nickel-titanium and beta-titanium wires are used for guided tooth movement,passive self-ligating bracket appliances can minimize frictional resistance.

Cordasco et al (2009)[13] performed an in vitro study to evaluate the frictional forces between bracket and archwire that included three passive self-ligating brackets (Damon SL). The brackets were individually bonded to a brass mount using a preformed 0.021 x 0.025 inch stainless steel wire jig in order to exclude adverse tipping or torsion. Thirty-six similar set-ups including in total 108 brackets were investigated using the same wire: copper (nickel-titanium) 0.014 inches. A testing machine was designed and constructed to measure the frictional forces between the wire and the three-bracket set-up. The frictional properties of two sets of 12 three-bracket set-ups (control) were tested and measured with an open slide and conventional ligation. A stainless steel ligature wire was used in the former, while elastomeric modules were employed in the latter. They found significant effect of ligation mode on the frictional properties of the three-bracket set-ups. Frictional forces arising from passive self-ligation were significantly lower than those resulting from elastic ligation. The same result was achieved when comparing self-ligation and metallic ligation. No significant difference was found when comparing elastic and metallic ligation.

Padhraig S. Fleming, AmaJohal (2010)[62] did a systematic review to evaluate the clinical differences in relation to the use of self-ligating brackets in orthodontics. Electronic databases were searched; Randomized controlled trials (RCTs) and controlled clinical trials (CCTs) investigating the influence of bracket type on alignment efficiency, subjective pain experience, bond failure rate, arch dimensional changes, rate of orthodontic space closure, periodontal outcomes, and root resorption were selected . Findings of this review shows that at this stage there is insufficient high-quality evidence to support the use of self-ligating fixed orthodontic appliances over conventional appliance systems or vice versa.

Stephanie Shih-HsuanChen et al (2010)[79] did a systematic review to identify the orthodontic literature with regard to the efficiency, effectiveness, and stability of treatment with self-ligating brackets compared with conventional brackets. Electronic search in 4 data bases were performed from 1966 to 2009, with supplemental hand searching of the references of retrieved articles. They concluded that despite claims about the advantages of self-ligating brackets, evidence is generally lacking. Shortened chair time and slightly less incisor proclination appear to be the only significant advantages of self-ligating systems over conventional systems that are supported by the current evidence.

Influence of Archwire: -shape, size and alloy types with frictional resistance.

Riley et al (1979)[69] compared frictional resistances of round and rectangular wires in plastic and metal brackets.Different dimensions of archwires used in orthodontic treatment were used in this study. They found more resistance with plastic than in the metal brackets. Friction increased with wire size and with time in a simulated oral environment.

Burstone (1981)[11] proposed the concept of “variable–modulus orthodontics” in which he reported superior orientation of tooth could be achieved with fewer wires by engaging archwires made of different alloy types with same cross section instead of varying the cross section of the wire. He introduced TMA wires to the orthodontic profession and claimed, the stiffness of 0.018” x 0.025” TMA wire was similar to 0.018” stainless steel wire. He suggested that the cross section of archwires could be maintained throughout the treatment by changing archwire materials of different stiffness to produce wide range of forces and load-deflection rates.

According to **Thurow (1982)**[87] allowing more clearance between the archwires and bracket slots by reducing the size of the wire relative to the slot of the bracket led to more tendencies towards bracket binding, which would increase the frictional resistance.

Baker et al (1987)[4] determined the magnitude of frictional force changes between several sizes of stainless steel orthodontic wires and an edgewise bracket. They created wet conditions by introducing artificial saliva. It was concluded that archwire dimensions more closely approximating that of the bracket slot decreased the potential for binding forms of friction.

D C Tidy (1989)[88] investigated frictional resistance to movement along a continuous arch wire. It was found that friction was proportional to applied load and inversely proportional to bracket width i.e. friction was greatest for narrow brackets. Arch wire dimension and slot size had little effect on friction. Nitinol and beta-titanium arch wire produced frictional forces two and five times greater than those of stainless steel.

Drescher et al (1989)[18] studied the effect of archwire material, archwire size, bracket width and biological resistance on the magnitude of friction. The following factors were found to affect friction at bracket-wire interface in the decreasing order - biological resistance, surface roughness of wire, wire size, bracket width and elastic properties. They concluded that the effective force has to be increased by two fold in Stainless steel, and six fold with Beta titanium to overcome friction when sliding mechanics is to be employed.

Angolkar PV, Kapila S (1990)[39] tested the effects of wire size and alloy on frictional force generated between bracket and wire during in-vitro translatory displacement of bracket relative to wire. Stainless steel (SS), cobalt-chromium (Co-Cr), nickel-titanium (NiTi), and beta-titanium (beta-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 0.018and 0.022-inch slots.Beta-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.

Ireland AJ, Sherriff M, McDonald F(1991)[33] compared friction in steel and ceramic brackets, using steel and nickel titanium wires of two sizes along with a new experimental polymeric wire in a buccal segment model constructed. The results indicate that friction during overjet reduction is minimized by using larger dimension rectangular wires and by using steel rather than nickel titanium wires.

Robert R Prososki et al (1991)[66] measured surface roughness and static frictional force resistance of orthodontic arch wires. Nine Nickel – titanium alloy archwires were studied, one Beta-titanium alloy wire, one stainless steel alloy wire and one Cobalt - Chromium alloy wire were included for comparison. The results showed that Cobalt – Chromium alloy and the nickel - titanium alloy wires, with the exception of Sentalloy and Orthonol, exhibited the lowest frictional resistance. The stainless steel alloy and the beta-titanium wires showed the highest frictional resistance. The stainless steel alloy wire was the smoothest wire tested, whereas NiTi, Marsenol and Orthonol were the roughest.

Saunders et al (1994)[71] stated that the archwire alloy rather than bracket product type or surface roughness influenced the frictional characteristics. Wires which had titanium as their constituent had higher frictional resistance than stainless steel or cobalt chromium archwires. Saliva tends to decrease the friction observed between titanium couples in each ceramic brackets that were tested. Multiple testing had no adverse effects on any archwire/bracket slot couples. For couples involving nickel titanium wires, however, the frictional tests actually polished the arch wires and created a smear layer on the surface of the bracket slot, which tended to reduce the friction.

Tselepis M, Brockhurst P, West VC (1994)[89] compared the dynamic frictional resistance between orthodontic brackets and arch wires, arch wire material, bracket material, bracket-to-arch wire angulation, and lubrication (artificial saliva). The frictional force involved in sliding a ligated arch wire through a bracket slot was measured with a universal testing machine. Of the four factors investigated, all were found to have a significant influence on friction. Polycarbonate brackets showed the highest friction and stainless steelbrackets the lowest. Friction increased with bracket-to-arch wire angulation. Lubrication significantly reduced friction. A range of 0.9 to 6.8 N frictional forces was recorded. The actual force values recorded were most useful for comparing the relative influence of the factors tested on friction, rather than as a quantitative assessment of friction in vivo. The forces observed suggest that friction may be a significant influence on the amount of applied force required to move a tooth in the mouth. Hence, arch wire and bracket selection may be an important consideration when posterior anchorage is critical.

Janet L Vaughan et al (1995)[90] studied the level of kinetic frictional forces generated during in-vitro translation at the bracket - wire interface with four different wires (stainless steel, cobalt - chromium, NiTi, Beta-Ti) with various cross - sections. The wires were ligated into the brackets with elastomeric ligatures. The results showed that for most wire sizes, lower frictional forces were generated with the stainless steel and cobalt-chromium wires than with the Beta-Titanium and NiTi wires. Increase in wire size generally resulted in increased friction. There were no significant differences between manufacturers for the sintered stainless steel brackets.

Ogata et al (1996)[61] evaluated the effects of different stainless steel brackets-wire combinations on kinetic friction with effects of second order deflections. They reported that kinetic frictional forces increased for every bracket-wire combination tested as the second order deflections increased. Frictional forces tended to be greater for rectangular wires than for round wires and increased with wire size. They further observed that frictional resistance appeared in two phases; with low deflections, a smooth sliding phase appeared in which friction increased in a linear manner. As the deflection increased, a binding phase occurred in which friction increased at a much greater rate and was not necessarily linear. The point at which binding occurred was different for each bracket-wire combinations. Therefore in cases of maximum anchorage, complete leveling was essential prior to sliding mechanics.

Michel berger DJ et al (2000)[57] tested the coefficients of friction of titanium and stainless steel brackets used in conjunction with stainless and ion-implanted beta-titanium archwires using a single contact interface between the brackets and archwires. Results showed that round stainless steel wires demonstrated lower coefficients of kinetic friction than the flat stainless steel wire surfaces.

K.Clocheret, G.Willems (2004)[38] studied the dynamic frictional behavior of orthodontic archwires and brackets. 15 different archwires and 16 different brackets using small oscillating displacements when opposed to a standard stainless steel bracket or a standard stainless steel wire were tested. Large number of different commercially available archwires and brackets when evaluated with the same apparatus according to the same protocol, allows a direct comparison of the different archwire and bracket combinations, and can assist in the choice of the optimal bracket-wire combination with regard to friction.

M. M. Moore, E. Harrington (2004)[51] measured the frictional forces created in association with two types of straight-wire bracket moving along stainless steel (SS) archwires. Forces were measured during translation of the bracket using an univers altesting machine. Steel and cobalt chromium brackets were tested in association with 0.019X0.025 and 0.021X0.025 inch stainless steel archwires at tips from 0-3 degrees. The main conclusion of the study was that space closure should be completed on a 0.019 × 0.025 inch archwire before a 0.021 × 0.025 inch wire is used to complete tooth alignment.

Kapur Wadhwa R, Kwon HK (2004)[41] compared in-vitro the static and kinetic frictional resistances of ceramic brackets with metal lined slots ("Clarity") and stainless steel brackets with archwires of two sizes (0.018 x 0.025 inch; 0.021 x 0.025 inch) of stainless steel (SS), nickel titanium (NiTi) and beta titanium (beta-Ti) wires. The results showed that the highest static and kinetic frictional resistances were found with the wide ceramic bracket, and with stainless steel and beta-Ti wires.

Haskova JE, Palmer G, Jones SP (2008)[29] studied the effects of static frictional resistance on varying the ligation technique in a Delta Force bracket system. Results revealed that the ligation pattern was found to be highly statistically significant in influencing frictional force.

Tecco S, Tete S & FestaF (2009)[85] did a study to test the null hypothesis that no statistically significant difference in frictional resistance is noted when round or rectangular archwires are used in conjunction with low-friction ligatures (small, medium, or large) or conventional ligatures. Total of 10 stainless steel brackets (0.022-in slot), and various orthodontic archwires, ligated with low-friction ligatures or conventional ligatures, were tested to compare frictional resistance. They concluded that low-friction ligatures show lower friction when compared with conventional ligatures when coupled with round archwires, but not when coupled with rectangular ones.

Michael Chung et al (2009)[55] examined the influence of third-order torque on kinetic friction in sliding mechanicsinvolving active and passive self-ligating brackets.Results showed that increasing the torque from 0* to 15* produced significant increases in frictional resistance with all sets of brackets and tubes tested. They concluded that third-order torque in posterior dental segments can generate frictional resistance during anterior retraction with the archwire sliding through self-ligating bracket slots. With small torque angles, friction is less with passive than with active self-ligating brackets, but bracket design is a factor. Frictional forces are substantial, regardless of ligation if the wire-slot torque exceedsthe third-order clearance.

Jones SP, Ben Bihi S (2009)[37] compared the static frictional resistance of a low-friction ligation system (Slide system) against a conventional elastomeric module, and studied the effect of storage in a simulated oral environment on the static frictional resistance of both ligation systems. Storage for 24 hours in artificial saliva had no effect on the static frictional resistance of conventional elastomeric modules and the Slide system. The claim by the manufacturer that the Slide system produces lower frictional resistance than conventional elastomeric modules is upheld.

Ligation methods and frictional resistance

Bedner et al (1991)[5] conducted an in-vitro study of simulated canine retraction to evaluate the difference in frictional resistance between stainless steel archwires against steel and ceramic brackets with elastomeric, steel and self-ligation. Under testing conditions, self-ligating steel brackets did not demonstrate less friction than the elastic or steel ligated brackets. Stainless steel brackets demonstrated the greatest friction when compared with other bracket-ligation technique combination.The clinical significance of this study becomes apparent when stainless steel brackets are used on the posterior teeth and ceramic brackets are used on the anterior teeth. If sliding mechanics are used, the anterior teeth may be more resistant to movement than the posterior teeth because of the greater friction of the ceramic brackets. This could result in more posterior anchorage loss than would be expected if only one type of bracket were used.

Taylor et al (1996)[84] tested the frictional resistance between brackets and archwires in the buccal segments using varying archwire dimensions, bracket material and ligation methods. Elastomeric ligatures produced larger forces while loosely tied stainless steel ligatures and active brackets produced the lowest frictional forces. They suggested that selection of ligation technique was crucial if friction had to be minimized and they advocated either a loosely ligated stainless steel ligature or the use of Active self-ligating brackets to reduce friction.

Max Hain et al (2003)[26] did an in-vitro study to examine the friction and stability of the polymeric coated modules with those of other common ligation methods. Six ligation methods (regular uncoated, slick [coated], conventional silver, easy-to-tie, silicone-impregnated, and standard silver modules) were used with standard stainless steel brackets and 0.019 X 0.025-in archwires, and resistance to movement was measured. Two self-ligating (Speed [Strite Industries, Cambridge, Ontario, Canada] and Damon [Sybron Dental Specialities Ormco, Orange, Calif]) brackets were also tested. Results showed the Damon self-ligating brackets produced less friction than the other ligation methods, followed by the coated modules. There was no significant difference between the frictional resistances of brackets ligated with regular uncoated, silicone-impregnated, and easy-to-tie modules. Speed self-ligating brackets produced less friction than regular uncoated, conventional silver, and standard silver modules. The frictional properties of coated modules were not significantly affected by repeating the test 5 times or by storage in saliva for a week. They concluded that Damon brackets produced no recordable friction of ligation. Coated modules produced 50% less friction than all other ligation methods except Damon. The coating was resistant to the simulated effects of the oral environment. Different methods of human saliva application were found to affect the frictional properties of the coating.

Nicholas, Turnbull and David J. Birnie (2007)[94] assessed the relative speed of archwire changes, comparing self-ligating brackets with conventional elastomeric ligation methods, and further assessed this in relation to the stage of orthodontic treatment represented by different wire sizes and types. They found out that the type of bracket and the size of wire used are statistically significant predictors for speed of ligation and chairside time. The self-ligating system offered quicker and arguably more efficient wire removal and placement for most orthodontic treatment stages.

Paola Gandini& Linda Orsib (2008)[64] tested the hypothesis that there is no difference between the frictional forces produced by a passive self-ligating bracket (SLB) in vitro and a conventional bracket (CB) used with two types of elastomeric ligatures. The brackets, wires and ligation methods used in-vitro were a passive SLB and a CB used with two types of elastomeric ligatures (conventional elastomeric ligature [CEL] and unconventional elastomeric ligatures [UEL]). The test found out that UELs may represent a valid alternative to passive SLBs for low-friction biomechanics.

Alan Petersen et al (2009)[1] Compared elastomeric ligatures (EL) vs self-ligating (SL) brackets in terms of their effects on the unloading force of a 0.014-inch Cu-NiTi aligning wire by simulating the alignment of a lingually malposed canine and using a full-arch design. Three ligation methods—SL, EL, and ‘‘relaxed’’ elastomeric ligature (REL) were tested with 30 wires per group.Results showed that wires ligated with EL and relaxed elastomeric ligature produced an average unloading force equal to 56% and 88%, respectively, of the same wire in an SL bracket. The unloading forces produced by a wire after force decay of the elastomers are not statistically different from the forces present in self-ligating systems.

John C. Voudouris (2010)[36] tested the frictional resistance forces (FRS) generated between several archwires and (1) interactive self-ligating (ISL) brackets and (2) conventionally ligated (CL) brackets.Frictional forces produced between three different archwire combinations and self-ligating (SL) brackets (ceramic and metal-slot or all-metal) and CL brackets (metalor ceramic) were evaluated in a dry environment. The three ISL brackets tested were In-Ovation C, In-Ovation-R, and Damon 3. The three CL brackets were Mystique with Neo Clip, Clarity, andOvation. Each bracket was tested with 0.020” SS, 0.019X0.025 SS and 0.018X0.018 coatedSS. The results of the test showed that the ISL ceramic brackets produced the lowest frictional resistance of all the self-ligating brackets. The CL ceramic brackets produced the greatest friction.

Sonia Kahlon et al (2010)[77] conducted an in-vitro study to compare the frictional resistance during sliding mechanics with Gianelly-type stainless steel working wires(0.016 X 0.022 and 0.018 X 0.022 in),Leone slide ligature, conventional elastic ligature, and stainless steel (SS) ligature, a conventional bracket and active and passive self-ligating brackets. Results showed that the Leone slide ligature showed less friction at both wire sizes than regular elastic ligation; however, it showed significantly more friction than both passive self-ligation (Damon) and conventional bracket with stainless steel ligation. Damon and conventional brackets with SS ligationbrackets produced no measurable friction with either 0.016 X 0.022-in or 0.018 X 0.022-in wires. An increase in wire size (from 0.016 X 0.022 to 0.018 X 0.022 in) led to an increase in friction in all bracket-archwire combinations.

MATERIALS AND METHODS

Materials used in this study

Brackets-Two popular brands in each Active and passive self-ligating bracket systems were selected and one conventional bracket system with elastomeric module ligation served as control.

Upper right first premolar stainless steel Roth prescription brackets with slot dimension of 0.022 x 0.028 inches were used in all the 3 groups. (Figure-1)

Active self-ligating bracket systems[79] -

a) Speed – (Strite industries -Canada)
b) In-Ovation R (GAC-Dentsply-USA)

Passive self-ligating bracket systems[44] -

a) Damon 3- (Ormco orthodontics-California)
b) Smart clip-(3 M Unitek-USA)

Conventional ligation system-

a) Mini Ovation-(GAC-Dentsply-USA)

Archwires -

a) 0.018 inches-A.J.wilcockStainless steel wires of straight length
b) 0.020 inches- A.J.wilcock Stainless steel wires of straight length
c) 0.017 x 0.025 inches-straight length Stainless steel wires(GAC-USA)
d) 0.019 x0.025 inches straight length Stainless steel wires (GAC-USA)
e) 0.021 x 0.025 inches- straight length Stainless steel wires (GAC-USA)

Elastomeric modules: Grey colored ligatures- (GAC-Dentsply-USA) (Fig-2)

Testing machine: Autograph AGS-J Series-Load cell capacity of 50 N-(Shimadzu- Corp Japan) (Fig-8)

Acetone: to condition the brackets before testing.

Study methodology

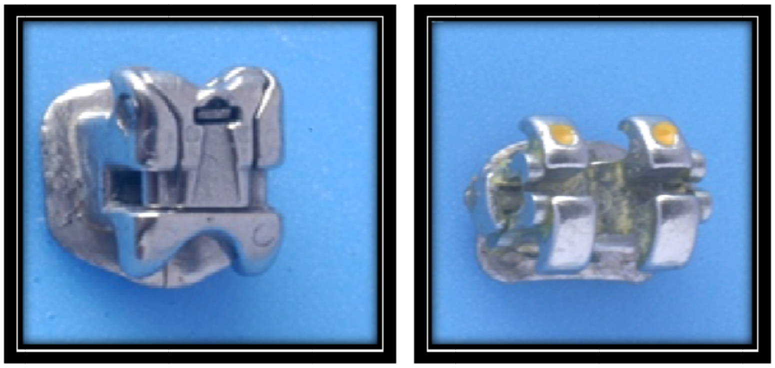
Two brackets of each type were bonded with epoxy resin adhesive (Araldite, Ciba-Geigy) to color coded acrylic rectangular blocks. The distance between the brackets measured 8 mm corresponding to interbracket width in clinical condition[44] (Fig-5). Prior to bracket bonding, a 0.021×0.025 inch diameter straight length wire was secured into the slot of the brackets of the self-ligating groups, and the twin preadjusted brackets as described by **Cordasco et al**[13] with a specially designed jig which enabled accurate paralleling of the bracket slot to the base of acrylic rectangular blocks (Fig-4). Each bracket and wire was cleaned with Acetone solution to remove any surface impurities before testing.

The straightened stainless steel archwires measuring 125 mm, after checking for any surface impurities or irregularities are ligated to the bracket groups. A universal testing machine was used to determine the frictional force levels in which the entire testing procedure was done in a dry environment.[51,89]

The acrylic rectangular blocks with bracket and archwire was then fixed vertically in the jaws of the Floor-mounted *AUTOGRAPH AGS*-J Series-Universal testing machine (Fig-8). Plumb line present on the testing machine ensured that the bracket slots and the archwire were parallel to the vertical pulling force of the testing machine (Fig-9). Care was taken not to twist the wire. The 50 N load cell was calibrated between 0 and 50 N and the archwire was drawn through the brackets.

Each archwire is pulled by a force of 2 N to a distance of 10 mm at a constant cross head speed of 1mm/minute[80] and the readings were recorded in Newtons (1N = 101. 97gms) for each bracket archwire combinations on the computer(Fig-7). The procedure was carried out with each bracket type and archwire for 10 times. A total of two hundred and fifty readings were recorded. To eliminate the influence of wear and notching of the archwire due to the testing procedure, each time a new arch wire was used for testing.[44]

To determine the absolute frictional resistance of the wire bracket couple, the relative kinetic frictional forces of each bracket-archwire couple were recorded and the collected data was statistically analyzed.



Damon **Smart Clip**

In-Ovation R **Speed**

Mini Ovation

Figure 1 : Brackets used in the study

Figure 2: Materials Used

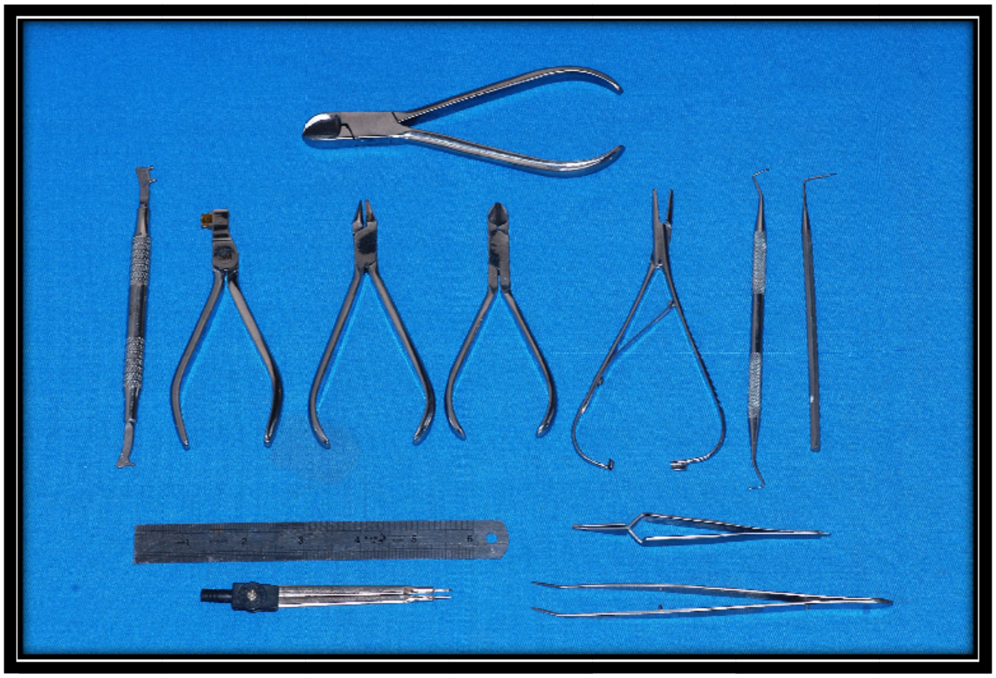


Figure 3 : Armamentarium

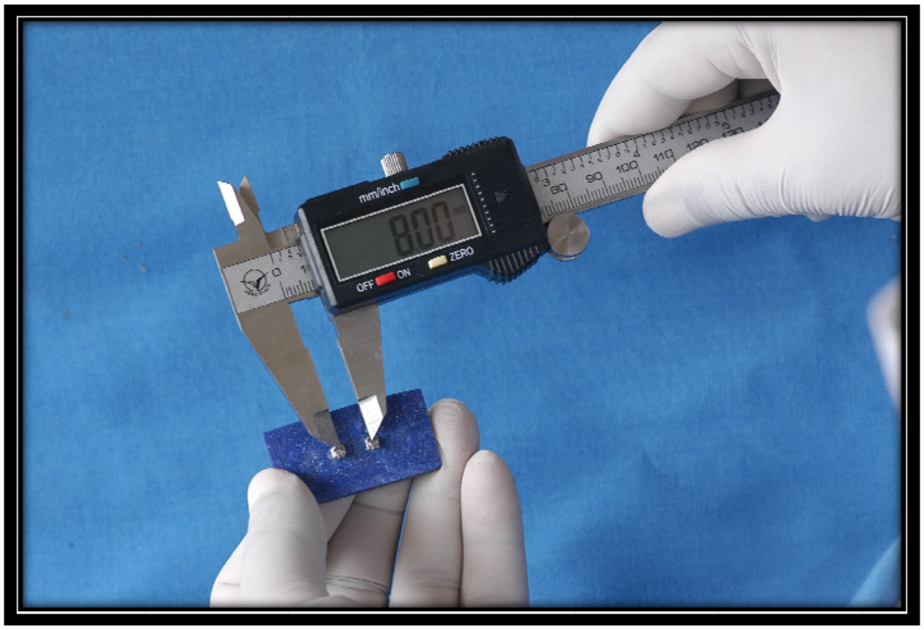


Figure 4: Bracket positioning with digital caliper

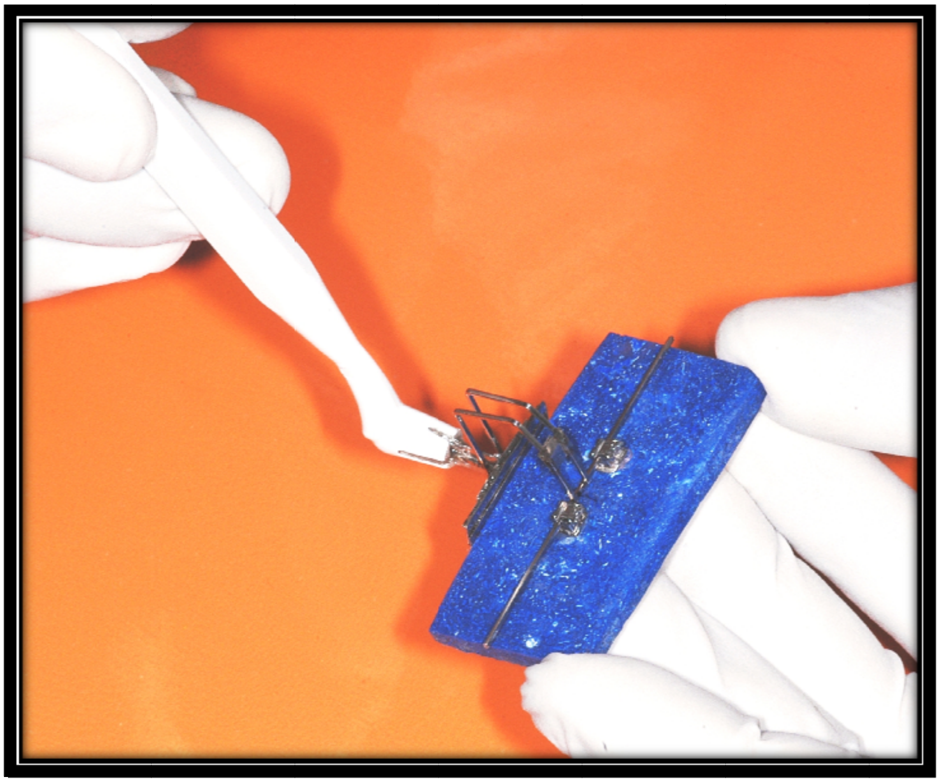


Figure 5: Bracket positioning with custom made jig

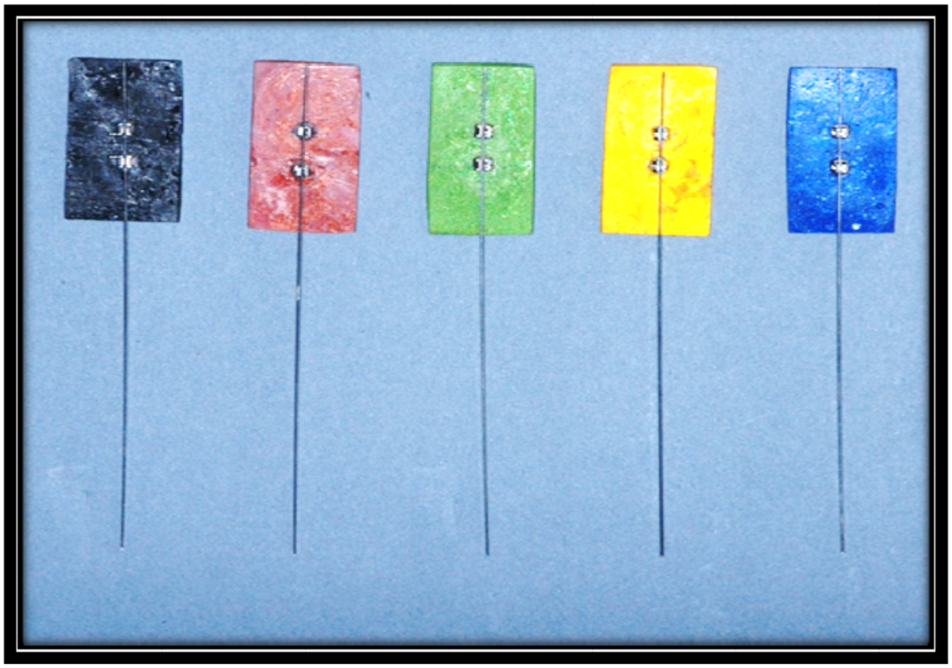


Figure 6 : Bracket Archwire assembly ready for testing

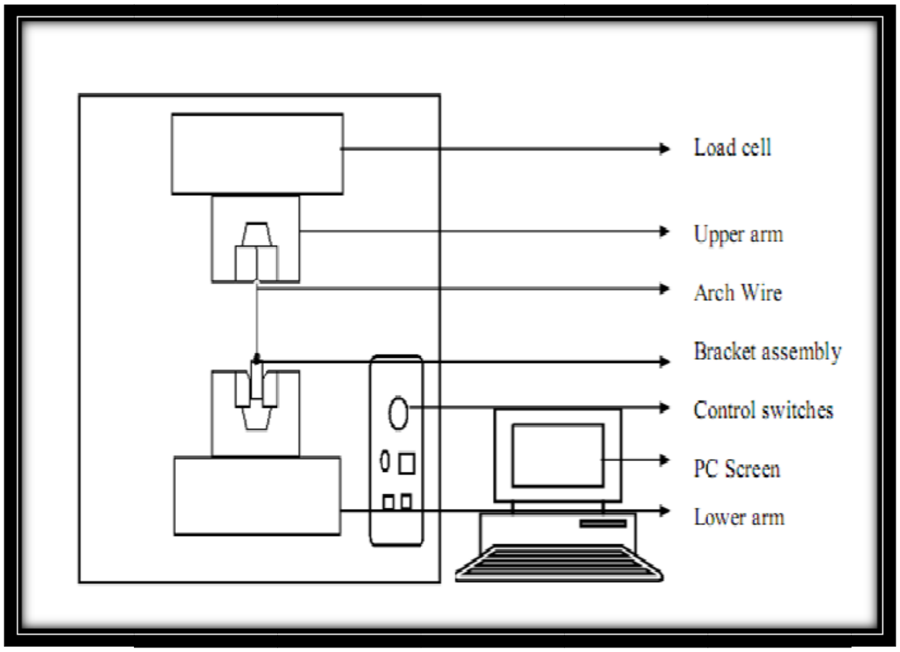


Figure 7 : Schematic representation of Test model assembly

Figure 8: Universal Testing Machine

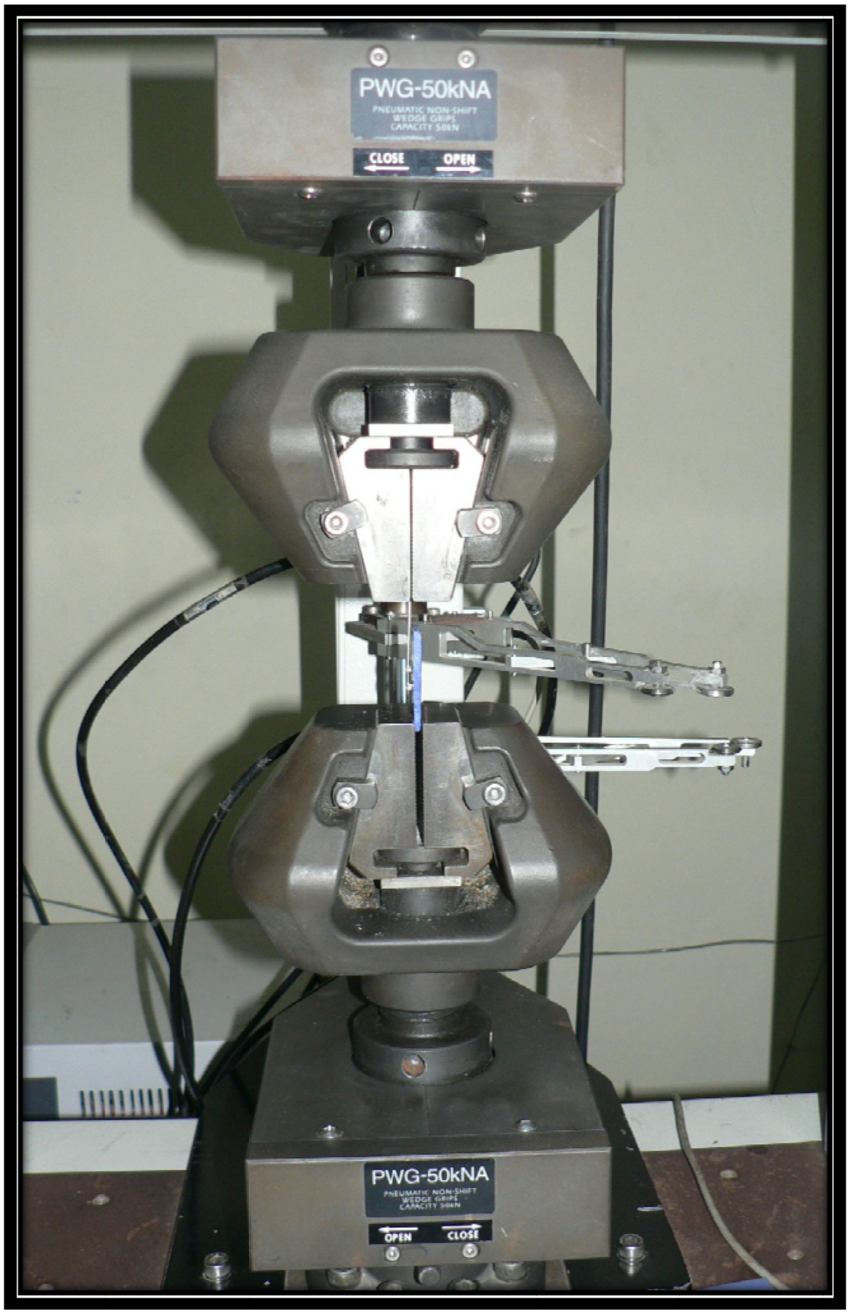
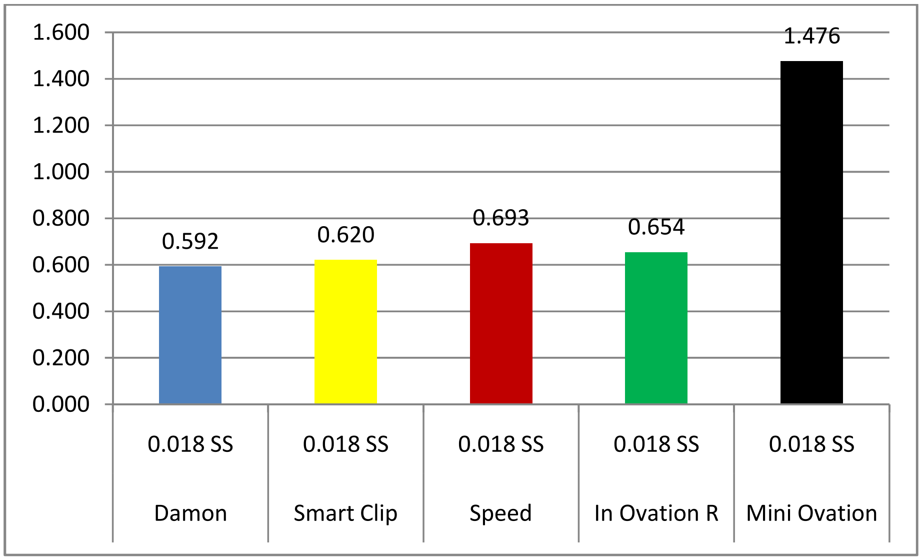
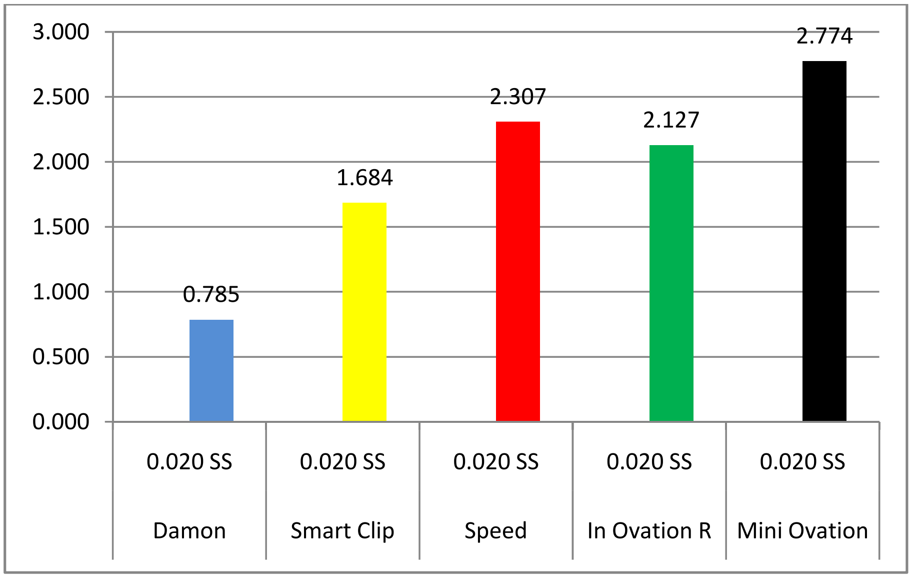


Figure 9 : Bracket Archwire assembly wire mounted on Testing Machine

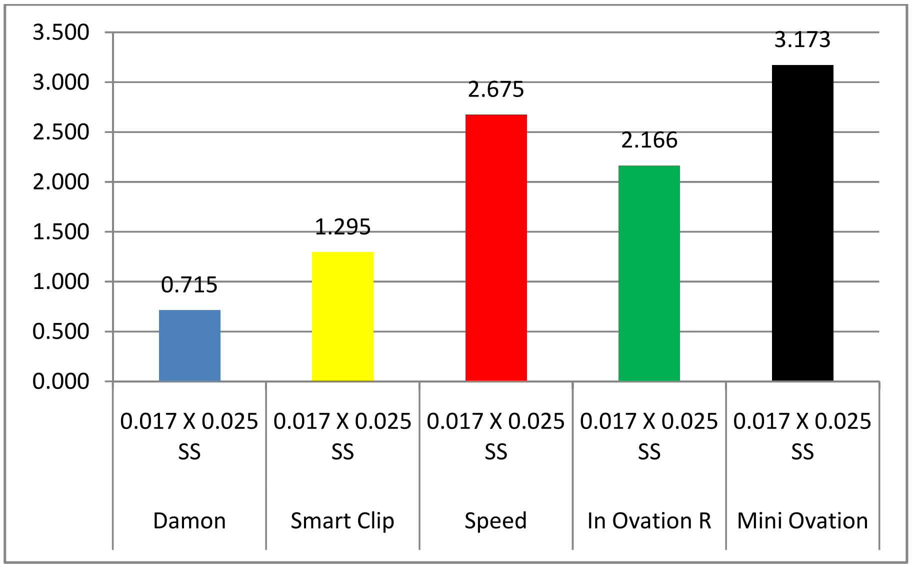
GRAPH 1 : Comparison of mean frictional resistance values of 0.018-inch Stainless steel wire



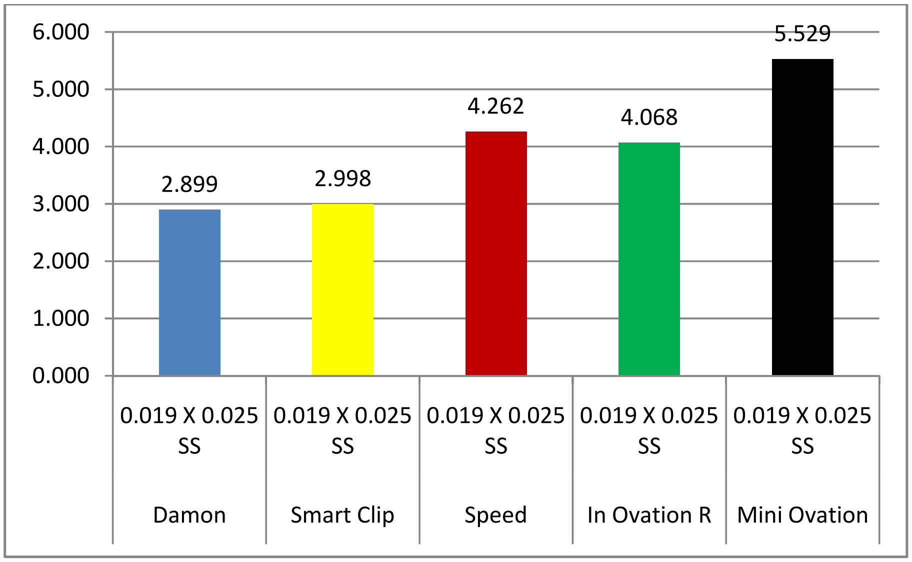
GRAPH 2 : Comparison of mean frictional resistance values of 0.020-inch Stainless steel wire



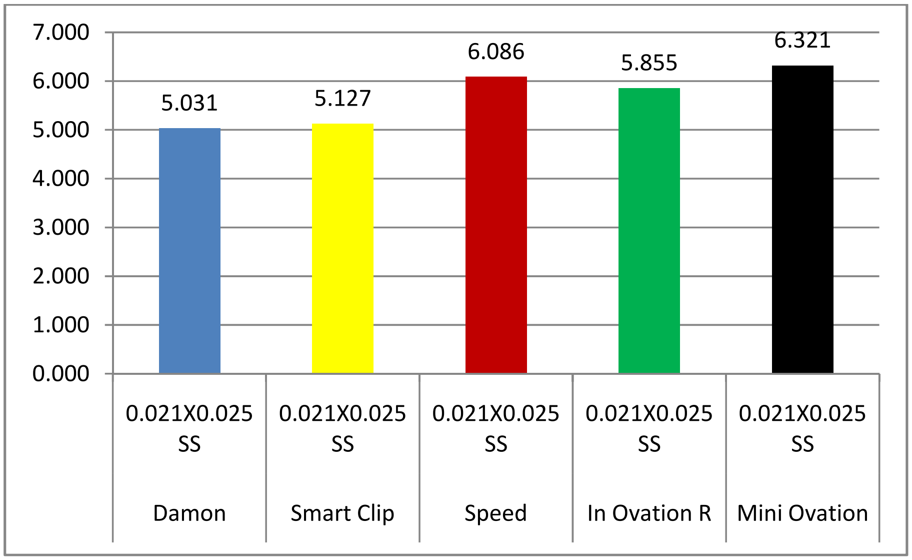
GRAPH 3 : Comparison of meanfrictional resistance values of 0.017 x 0.025-inch Stainless steel wire



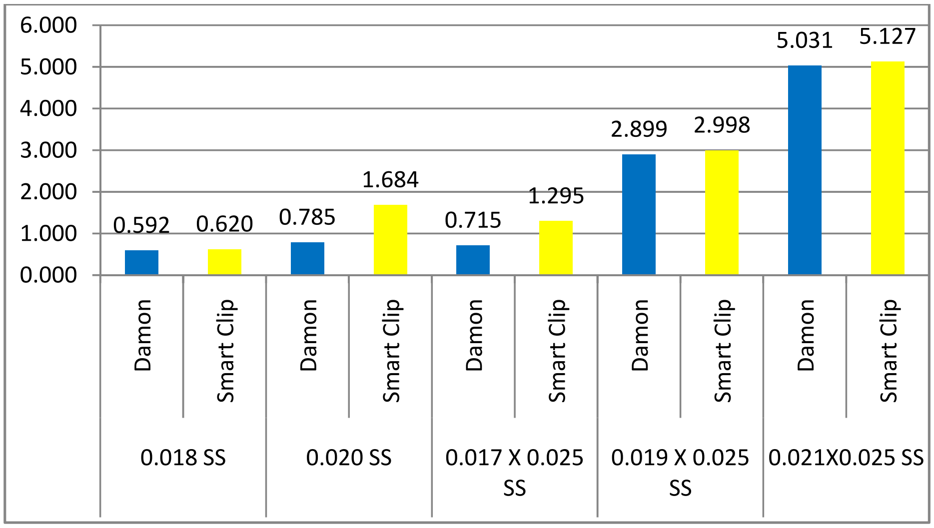
GRAPH 4 Comparison of mean frictional resistance values of 0.019 x 0.025-inch Stainless steel wire



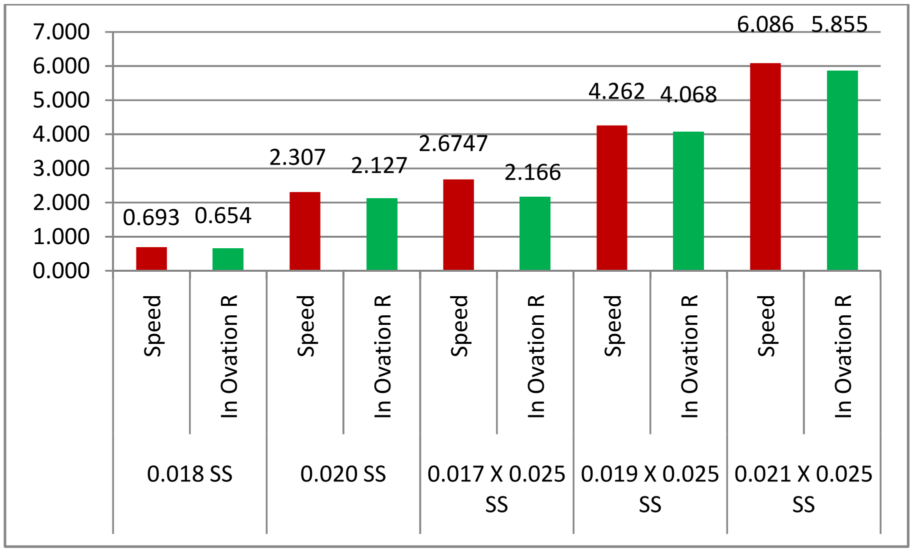
GRAPH 5 : Comparison of meanfrictional resistance values of 0.021 x 0.025-inch Stainless steel wire



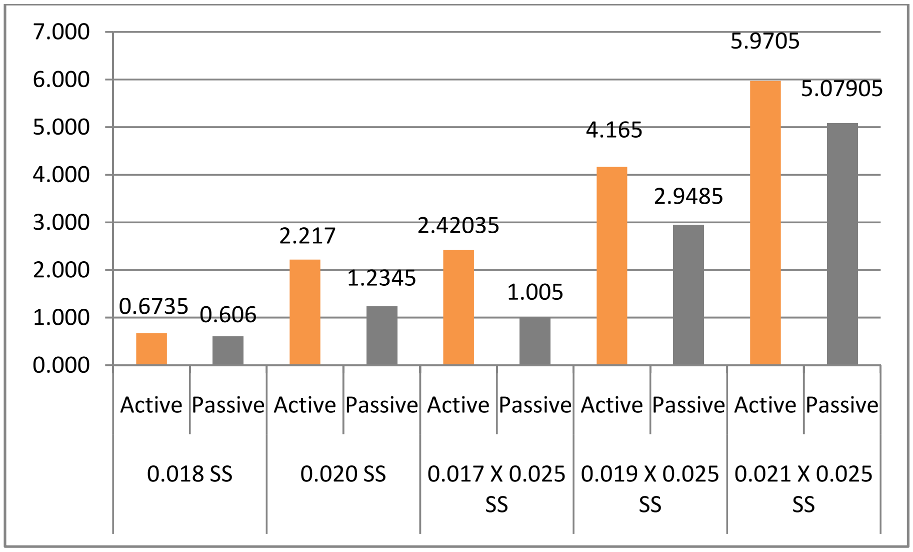
GRAPH 6:T-test result comparison Mean Frictional resistance:- Passive Versus Passive System



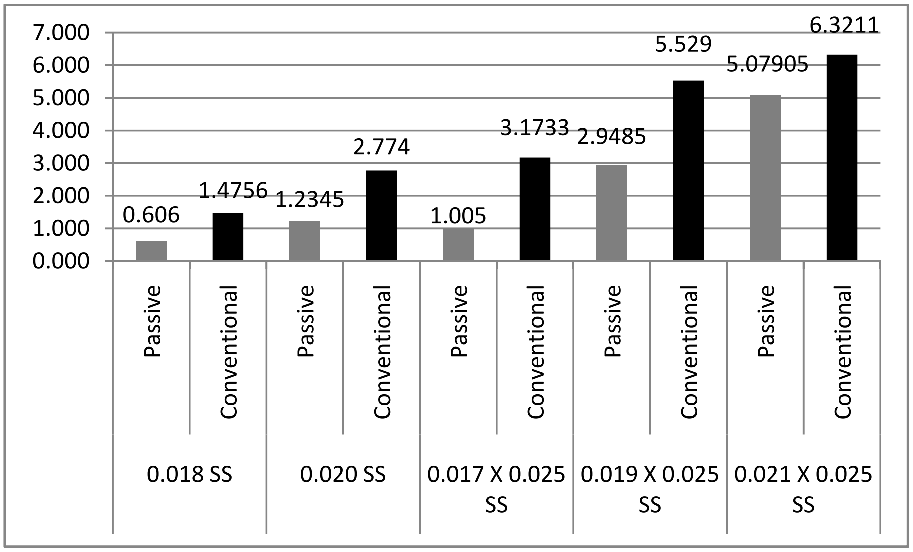
GRAPH 7: T-test result comparison ofMean Frictional resistance:-Active versus Active system



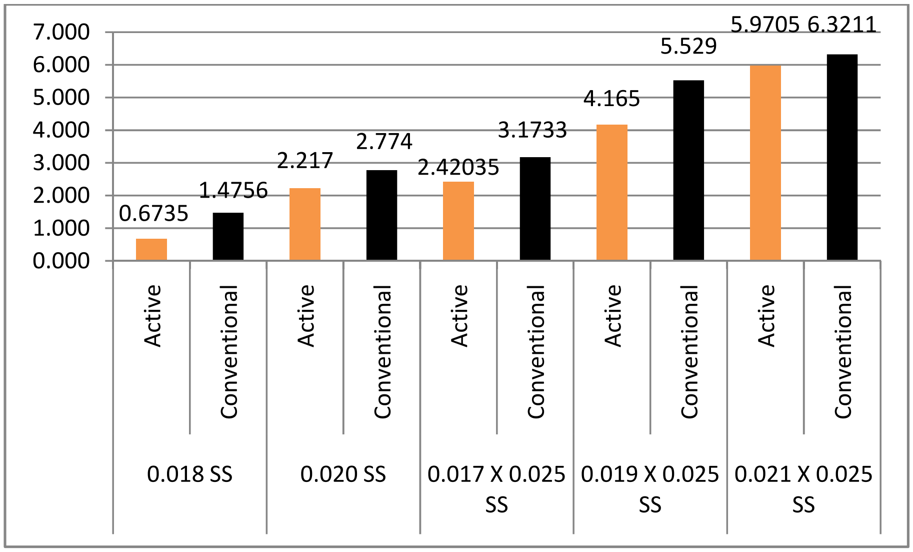
GRAPH 8: T-test result comparison ofMean Frictional resistance:-Active versus Passive system



GRAPH 9: T-test result comparison of Mean Frictional resistance:-Passive versus Conventional system



GRAPH 10: T-test result comparison ofMean Frictional resistance:- Active versus Conventional system



RESULTS

The present study was conducted to evaluate the kinetic frictional resistance of four self-ligating brackets:- two Active types, two Passive types and to compare the values with that of a conventional twin bracket ligated with elastomeric module. The brackets were tested against five different dimensions of round and rectangular stainless steel wires. Thus twenty five bracket archwire couples and two hundred and fifty total readings were obtained.

These test readings were statistically analyzed with a one way ANOVA followed by Post HOC Tukey test for multiple comparisons and student T tests. (The level of statistical significance was set at $p=0.05$. If the value of $P>0.05$, then the inference is that there is no statistical difference between the variables and a value of $P<0.05$, implies a statistically significant difference between the variables).

The statistical operations were done through SPSS (Statistical Package for Social Sciences Software) for Windows, version 10.0 (SPSS, 1999. SPSS Inc: New York) and formulated in tables and bar diagrams.

One way ANOVA evaluation with mean frictional resistance force values for bracket archwire couples:-Damon brackets with total mean value of **2.0044 N** showed least kinetic frictional resistance to sliding movement followed by

SmartClip- **2.34482 N**, In-ovation- **2.9740 N** and Speed with **3.2045 N** respectively. Maximum resistance of **6.3211 N** was recorded for conventional twin brackets ligated with elastomeric modules (Table-1) & (Graphs-1-5).

Post Hoc Tukey HS tests:

Post Hoc Tukey HS test for multiple comparisons showed no statistically significant difference in frictional resistance for **0.018-inch** stainless steel wire within the self-ligating bracket groups (P>0.05), whereas conventional twin brackets showed significant increase in frictional resistance (P<0.001) (Table-2).

When comparing various bracket groups with **0.020-inch** stainless steel wire, no statistically significant difference in the values were seen between the Speed and the In-Ovation brackets (P>0.05) (Active group), whereas all other groups showed statistically significant difference in frictional resistance (P<0.01), (Table-3).

For **0.017 X 0.025-inch** stainless steel wire, all the brackets tested (Self-ligating and conventional) showed highly significant levels of difference in frictional resistance (P<0.001). Damon brackets showed least frictional resistance to sliding movement and the frictional resistance increased with SmartClip, In-ovation and Speed respectively. Maximum resistance was recorded with conventional twin brackets ligated with elastomeric modules (Table-4).

For **0.019 X 0.025-inch** stainless steel wire there was no statistically significant difference in the frictional resistance between Damon and SmartClip ($P>0.05$) (Passive self-ligating groups). Other bracket groups showed statistically significant difference in frictional resistance ($P<0.01$), (Table-5).

With **0.021 X 0.025-inch** stainless steel wire there was no statistically significant difference between Damon and SmartClip ($P>0.05$) (Passive self-ligating group) whereas all the other brackets showed significant difference in the mean frictional resistance values ($P<0.001$) (Table-6).

Student T Tests

Student T Test was done to individually compare,

A) Passive system versus Passive system

B) Active system versus Active system

C) Active system versus Passive system

D) Passive system versus Conventional system &

E) Active system versus Conventional system.

Among the **Passive** self-ligation group Damon brackets exhibited less frictional resistance than SmartClip for all the wires tested. The mean difference in resistance was statistically significant for all wires ($P<0.05$) except for 0.018-inch stainless steel wire which was not significant ($P>0.05$), (Table-7) & (Graph-6).

Among the **Active** self-ligating group In-ovation showed least frictional resistance for all the wires tested and the difference in the mean was statistically significant(P<0.001) except for 0.020-inch wire which was not significant (P>0.05), (Table-8) & (Graph-7).

When comparing **Active** versus **Passive** self-ligating systems, it was noticed that the Active systems showed comparatively higher frictional resistance than the Passive systems for all the archwires tested. The mean difference between the two systems were highly significant (P<0.001), (Table-9) & (Graph-8).

Conventional twin brackets showed high frictional resistance values when compared with both Active and Passive self-ligating brackets for all the wires tested. The difference in the frictional resistance between these two groups were highly significant (P<0.001), (Table-10,11) & (Graph-9,10).

Table 1: Mean kinetic frictional resistance for bracket archwire couples.

Bracket		N	Mean	Std. Deviation	95% Confidence Interval for Mean	
					Lower Bound	Upper Bound
Damon	0.018 SS	10	.59200	.056921	.55128	.63272
	0.020 SS	10	.78500	.031002	.76282	.80718
	0.017 X 0.025 SS	10	.71500	.025927	.69645	.73355
	0.019 X 0.025 SS	10	2.89900	.060818	2.85549	2.94251
	0.021 X 0.025 SS	10	5.03100	.069992	4.98093	5.08107
	Total	50	2.00440	1.756452	1.50522	2.50358
Smart Clip	0.018 SS	10	.62000	.031623	.59738	.64262
	0.020 SS	10	1.68400	.049710	1.64844	1.71956
	0.017 X 0.025 SS	10	1.29500	.055227	1.25549	1.33451
	0.019 X 0.025 SS	10	2.99800	.058271	2.95632	3.03968
	0.021 X 0.025 SS	10	5.12710	.113593	5.04584	5.20836
	Total	50	2.34482	1.610050	1.88725	2.80239
Speed	0.018 SS	10	.69300	.022632	.67681	.70919
	0.020 SS	10	2.30700	.072885	2.25486	2.35914
	0.017 X 0.025 SS	10	2.67470	.150787	2.56683	2.78257
	0.019 X 0.025 SS	10	4.26200	.136329	4.16448	4.35952
	0.021 X 0.025 SS	10	6.08600	.162972	5.96942	6.20258
	Total	50	3.20454	1.856127	2.67703	3.73205
In Ovation R	0.018 SS	10	.65400	.029889	.63262	.67538
	0.020 SS	10	2.12700	.294771	1.91613	2.33787
	0.017 X 0.025 SS	10	2.16600	.071988	2.11450	2.21750
	0.019 X 0.025 SS	10	4.06800	.072999	4.01578	4.12022
	0.021 X 0.025 SS	10	5.85500	.073824	5.80219	5.90781
	Total	50	2.97400	1.826284	2.45498	3.49302
Mini Ovation	0.018 SS	10	1.47560	.047303	1.44176	1.50944
	0.020 SS	10	2.77400	.099353	2.70293	2.84507
	0.017 X 0.025 SS	10	3.17330	.105740	3.09766	3.24894
	0.019 X 0.025 SS	10	5.52900	.142858	5.42681	5.63119
	0.021 X 0.025 SS	10	6.32110	.035529	6.29568	6.34652
	Total	50	3.85460	1.819352	3.33755	4.37165

Post Hoc Tests- Table 2:Tukey HSD for Multiple Comparisons

0.018 inch SS wire with Brackets:

Wire	**(I) Bracket**	**(J) Bracket**	**Mean Difference (I-J)**	**P – Value.**
0.018 SS	**Damon**	**Smart Clip**	**-0.028000**	**0.520**
		Speed	-0.101000*	<0.001
		In Ovation R	-0.062000*	0.009
		Mini Ovation	-0.883600*	<0.001
0.018 SS	**Smart Clip**	Speed	-0.073000*	<0.001
		In Ovation R	**-0.034000**	**0.325**
		Mini Ovation	-0.855600*	<0.001
0.018 SS	**Speed**	**In Ovation R**	**0.039000**	**0.200**
		Mini Ovation	-0.782600*	<0.001
0.018 SS	In Ovation R	Mini Ovation	-0.821600*	<0.001

Table 3: Tukey HSD for Multiple Comparisons

0.020 inch SS wire with Brackets:

Wire	**(I) Bracket**	**(J) Bracket**	**Mean Difference (I-J)**	**P – Value**
0.020 SS	Damon	Smart Clip	-0.899000*	<0.001
		Speed	-1.522000*	<0.001
		In Ovation R	-1.342000*	<0.001
		Mini Ovation	-1.989000*	<0.001
0.020 SS	Smart Clip	Speed	-0.623000*	<0.001
		In Ovation R	-0.443000*	<0.001
		Mini Ovation	-1.090000*	<0.001
0.020 SS	**Speed**	**In Ovation R**	**0.180000**	**0.059**
		Mini Ovation	-0.467000*	<0.001
0.020 SS	In Ovation R	Mini Ovation	-0.647000*	<0.001

Table 4: Tukey HSD for Multiple Comparisons

0.017 X 0.025 inch SS wire with Brackets:

Wire	**(I) Bracket**	**(J) Bracket**	**Mean Difference (I-J)**	**P – Value.**
0.017 X 0.025 SS	Damon	Smart Clip	-0.580000*	<0.001
		Speed	-1.959700*	<0.001
		In Ovation R	-1.451000*	<0.001
		Mini Ovation	-2.458300*	<0.001
0.017 X 0.025 SS	Smart Clip	Speed	-1.379700*	<0.001
		In Ovation R	-0.871000*	<0.001
		Mini Ovation	-1.878300*	<0.001
0.017 X 0.025 SS	Speed	In Ovation R	0.508700*	<0.001
		Mini Ovation	-0.498600*	<0.001
0.017 X 0.025 SS	In Ovation R	Mini Ovation	-1.007300*	<0.001

Table 5: Tukey HSD for Multiple Comparisons

0.019 X 0.025 inch SS wire with Brackets:

Wire	**(I) Bracket**	**(J) Bracket**	**Mean Difference (I-J)**	**P – Value**
0.019 X 0.025 SS	**Damon**	**Smart Clip**	**-0.099000**	**0.205**
		Speed	-1.363000*	<0.001
		In Ovation R	-1.169000*	<0.001
		Mini Ovation	-2.630000*	<0.001
0.019 X 0.025 SS	Smart Clip	Speed	-1.264000*	<0.001
		In Ovation R	-1.070000*	<0.001
		Mini Ovation	-2.531000*	<0.001
0.019 X 0.025 SS	Speed	In Ovation R	0.194000*	0.001
		Mini Ovation	-1.267000*	<0.001
	In Ovation R	Mini Ovation	-1.461000*	<0.001

Table 6: Tukey HSD for Multiple Comparisons

0.021 X 0.025 inch SS wire with Brackets:

Wire	(I) Bracket	(J) Bracket	Mean Difference (I-J)	P – Value.
0.021 X 0.025 SS	**Damon**	**Smart Clip**	**-0.096100**	**0.227**
		Speed	-1.055000*	<0.001
		In Ovation R	-.824000*	<0.001
		Mini Ovation	-1.290100*	<0.001
0.021 X 0.025 SS	Smart Clip	Speed	-0.958900*	<0.001
		In Ovation R	-0.727900*	<0.001
		Mini Ovation	-1.194000*	<0.001
0.021 X 0.025 SS	Speed	In Ovation R	0.231000*	<0.001
		Mini Ovation	-0.235100*	<0.001
0.021 X 0.025 SS	In Ovation R	Mini Ovation	-0.466100*	<0.001

Table 7:–student T-test to compare Passive system versus

Passive system

Wire	Bracket	N	Mean	SD	P – Value
0.018 SS	**Damon**	**10**	**0.59200**	**0.056921**	**0.191**
	Smart Clip	**10**	**0.62000**	**0.031623**	
0.020 SS	Damon	10	0.78500	0.031002	<0.001
	Smart Clip	10	1.68400	0.049710	
0.017 X 0.025 SS	Damon	10	.71500	0.025927	<0.001
	Smart Clip	10	1.29500	0.055227	
0.019 X 0.025 SS	Damon	10	2.89900	0.060818	0.002
	Smart Clip	10	2.99800	0.058271	
0.021 X 0.025 SS	**Damon**	**10**	**5.03100**	**0.069992**	**0.038**
	Smart Clip	**10**	**5.12710**	**0.113593**	

Table 8:–student T-test result comparison of Active system versus

Active system

Wire	Bracket	N	Mean	SD	P – Value
0.018 SS	Speed	10	0.69300	0.022632	0.004
	In Ovation R	10	0.65400	0.029889	
0.020 SS	**Speed**	**10**	**2.30700**	**0.072885**	**0.077**
	In Ovation R	**10**	**2.12700**	**0.294771**	
0.017 X 0.025 SS	Speed	10	2.67470	0.150787	<0.001
	In Ovation R	10	2.16600	0.071988	
0.019 X 0.025 SS	Speed	10	4.26200	0.136329	0.001
	In Ovation R	10	4.06800	0.072999	
0.021 X 0.025 SS	Speed	10	6.08600	0.162972	0.001
	In Ovation R	10	5.85500	0.073824	

Table- 9:- student T-test result comparison of Active system versus Passive system

Wire	**Group**	**N**	**Mean**	**SD**	**P – Value**
0.018 SS	Active	20	0.67350	0.032650	<0.001
	Passive	20	0.60600	0.047061	
0.020 SS	Active	20	2.21700	0.228475	<0.001
	Passive	20	1.23450	0.462937	
0.017 X 0.025 SS	Active	20	2.42035	0.285173	<0.001
	Passive	20	1.00500	0.300482	
0.019 X 0.025 SS	Active	20	4.16500	0.145712	<0.001
	Passive	20	2.94850	0.077070	
0.021 X 0.025 SS	Active	20	5.97050	0.170895	<0.001
	Passive	20	5.07905	0.104226	

Table 10:- student T-test result comparison of Passive system versus Conventional system

Wire	**Group**	**N**	**Mean**	**SD**	**P – Value**
0.018 SS	Passive	20	0.60600	0.047061	<0.001
	Conventional	10	1.47560	0.047303	
0.020 SS	Passive	20	1.23450	0.462937	<0.001
	Conventional	10	2.77400	0.099353	
0.017 X 0.025 SS	Passive	20	1.00500	0.300482	<0.001
	Conventional	10	3.17330	0.105740	
0.019 X 0.025 SS	Passive	20	2.94850	0.077070	<0.001
	Conventional	10	5.52900	0.142858	
0.021 X 0.025 SS	Passive	20	5.07905	0.104226	<0.001
	Conventional	10	6.32110	0.035529	

Table11:- student T-test result comparison of Active system versus Conventional system

Wire	**Group**	**N**	**Mean**	**SD**	**P – Value**
0.018 SS	Active	20	.67350	0.032650	<0.001
	Conventional	10	1.47560	0.047303	
0.020 SS	Active	20	2.21700	0.228475	<0.001
	Conventional	10	2.77400	0.099353	
0.017 X 0.025 SS	Active	20	2.42035	0.285173	<0.001
	Conventional	10	3.17330	0.105740	
0.019 X 0.025 SS	Active	20	4.16500	0.145712	<0.001
	Conventional	10	5.52900	0.142858	
0.021 X 0.025 SS	Active	20	5.97050	0.170895	<0.001
	Conventional	10	6.32110	0.035529	

DISCUSSION

Friction can be defined as a force that resists motion between two objects that are in contact with each other and it is always parallel to the surfaces that are in contact. Smoother surfaces exhibit less friction, while rougher surfaces exhibit more friction. Friction exists in two forms Static and Kinetic friction.[2]

Static friction is the resistance that prevents actual motion and kinetic friction is the resistance which exists during motion. When two surfaces in contact slide or tend to slide against each other, two components of total force arise, one is the frictional force component and the other is the normal force component. The direction of the frictional force is always parallel and opposite to the sliding motion.[58]

In clinical situations, the tooth movement is initiated in the alveolar socket when the retraction force overcomes the resistance force of the periodontal supporting structures and the frictional forces in the bracket.[46] Initially, upon appliance activation the delivered force is sufficient to overcome the frictional forces and tooth movement takes place. This movement continues until the resistance of the deformed periodontal support structure builds to a value which, when added to the kinetic force, offsets the delivered force.

Optimal force magnitude during orthodontic treatment will result in proper tissue response and rapid tooth movement. Also optimum force levels stimulate cellular activity without completely occluding blood vessels in the periodontal ligament. Higher forces are likely to create a hyalinized avascular area that must be revascularized before the next phase. During mechanotherapy involving movement of the wire along the brackets, friction at the bracket-archwire interface might prevent attaining optimal force levels in the supporting tissues.[10]

Frictional forces in continuous arch mechanics must be overcome for a favorable periodontal response intended for tooth movement. It has been proposed that approximately 50% of the force applied to slide a tooth is used to overcome friction.[65] The different mechanical variables that influence force levels are the bracket material composition, size and width of the slot the size, shape, stiffness and surface texture of the archwire, ligation of the archwire to the bracket with ligature wire, elastomeric modules. [8, 18,46,47,78]

Self-ligating brackets were introduced in the mid-1930's to overcome the drawbacks of conventional ligation in the form of Russell attachment, [34] which was intended to reduce ligation time, reduce friction and improve operator efficiency. These are ligature less bracket systems that have a mechanical device built into the bracket to close off the edgewise slot. From the patient's perspective, self-ligating brackets are generally smoother, more comfortable, easier to clean, prevents food trap because of the absence of wire ligature is another significant advantage as previously reported by **Eberting,** [19] **Michelberger,**[57] **and Simona Tecco.**[74]

From the biomechanical and technical point of view, self-ligating brackets offer good seating of the arch wire in the bracket slot and thereby effective use of the arch wire and bracket properties, low friction between bracket and archwire, less force application, and faster archwire removal and ligation.[28, 43]

Several studies have demonstrated a significant decrease in friction for self-ligating brackets, compared with conventional bracket designs.[50,73] Such a reduction in friction can help shorten overall treatment time, especially in extraction patients in whom tooth translation is achieved by sliding mechanics.[19] **Micheal Alpern**[56] stated that low friction is required to slide teeth along an archwire with minimum resistance during initial tooth alignment stage and to open or close dental spaces.

Self-ligating brackets can be categorized into 2 types-

A. Active systems -those that have a spring clip that presses against the archwire, such as the In-Ovation (GAC Intl, NY), Speed (Strite Industries, Canada),[79]

B. Passive systems-those in which the self-ligating clip does not press against the wire such as Damon SL (Ormco/A company), SmartClip (3M Unitek).[44]

With every self-ligating bracket whether active or passive the movable fourth wall of the bracket is used to convert the archwire slot into a tube. The cap of the self-ligating brackets retains the original form throughout treatment, whereas elastomeric ligatures lose the initial shape and tightness and force decay. This was documented from the studies of **Taloumis**[83] and **Micheal berger DJ** [57]

The active clip in the active type of self-ligating brackets offers light continuous force when the arch wire is pressed in the bracket slot during the aligning and leveling phase of the treatment. This helps better torque expression than the passive self-ligating brackets.[3,63] Some active clips are active only with larger archwire sizes, in their passive state; however, they decrease the lumen of the slot.[28] The smaller the lumen of the archwire slot, the greater the friction when using a light wire in a distorted occlusion. Friction is also greater with sliding mechanics when a larger working wire is used[9] because the archwire is actively seated to the base of the slot.

Passive self-ligating brackets have the advantage of lower bracket archwire binding and frictional resistance and hence the net tooth moving force is predictably low and the reciprocal forces are also correspondingly low.[28] This helps in less anchorage loading. Alignment of severely irregular teeth and the resolution of severe rotations are made easier with the above mentioned property but these type of brackets offers less torque control.[3]

Steven Budd[80] compared the frictional resistance of four self-ligating brackets and showed that the passive system brackets has less friction to sliding movement. This was supported with the study of **Cordasco**[13] who also found that the frictional resistance of passive self-ligating brackets are lower than Conventional brackets ligated with elastomeric modules. However, considerable variation exists between commercially available bracket types in terms of their mechanical, geometric, and material-related specifications, and this would be expected to affect their frictional performance.[80]

Friction can be studied in a number of ways. In some instances wires are pulled through at least one bracket[26,46] and in some other instances brackets were slid on the wires.[5,24] In the present study Self-ligating brackets were divided into two groups-Active clip type (**In-Ovation-** (GAC Intl, NY) & **SPEED**-(Strite Industries, Ontario, Canada)) and Passive clip type (**Damon SL** –Ormco “A” Company) & **SmartClip**-(3M Unitek United States)) whereas preadjusted twin bracket **Mini Ovation**-(GAC Intl,NY) with elastomeric module ligation served as control. Two brackets in each groups were attached to acrylic blocks with bracket slots kept parallel to each other to avoid binding of the wire.

These brackets were tested for their kinetic frictional resistance offered to stainless steel archwires. Five types of Stainless steel wires with varying dimensions were used such as 0.018-inch, 0.020-inch, 0.017 x 0.025-inch, 0.019 x 0.025-inch & 0.021 X 0.025-inch wires. These wire dimensions are predominantly used in orthodontic treatment with preadjusted straight wire appliances.

An Universal testing machine (Autograph AGS-J Series- SHIMADZU Corporation-Japan) with load cell of 2N, Crosshead speed of 1 mm/minute & Crosshead speed accuracy of ±0.5% or ±0.025mm/min (0.001in/min) was used to measure the frictional resistance values.[8, 53, 77]

Results showed that in both passive and active groups, frictional resistance properties showed discernable variations as the dimension of the wires changed. Statistically- One-way ANOVA showed that the interactions between bracket and archwire alloy were highly significant for friction- (Table-1).

Both Passive self-ligating brackets had significantly lower frictional forces than two Active self-ligating brackets tested for all combination of archwires, whereas twin brackets with conventional ligation exhibited the maximum values for all the archwires tested.

Damon SL has a labial slide with the leading edge designed to capture the archwire in the slot; on closure, it forms a tube with 0.022 X 0.028 inches inside the bracket.[28] The Passive slide doesn't apply a ligation force to the archwire but only cover the slot, to restrain the archwire.[15] SmartClip bracket consists of two NiTi clips which open and close through elastic deformation of the material, when the archwire exerts force on the clip. This arrangement also facilitates free movement of the archwire inside the bracket.[32] These factors may account for the reduced frictional forces shown by these passive self-ligating brackets with all the archwire samples tested.[15, 56]

Both Active Self-ligating systems; In-Ovation R and Speed, showed increase in frictional forces than the passive systems but were less than elastomeric module ligated conventional twin brackets. This was in accordance with previous studies done by **Thorstenson et al**[25] and **Harradine**.[28]

In-Ovation incorporates a sliding Cobalt-Chromium active clip, which encroaches on the slot from the labial aspect, potentially placing an active force on the archwire. The Speed bracket has an active NiTi clip that flexes and rolls over the archwire. The positive contact of the active spring clip with the archwire in the active systems is likely to produce higher friction than the passive appliance designs.[50]

Most authors reported that the conventional twin brackets ligated with elastomeric modules exhibit high frictional resistance than self-ligating brackets when tested in both dry and wet atmospheres. [20, 73, 75]

There was an increase in the frictional force value with increase in wire dimension; in this study 0.018 inch round wire exhibited the least friction, whereas 0.020, 0.017 x 0.025 & 0.019 x 0.025 inch rectangular wire showed more friction (Table-1) and 0.021 x 0.025 inch rectangular stainless steel wires showed the maximum friction. Higher frictional values when increasing wire dimensions were demonstrated in many previous studies.[8, 9, 10]

However in Passive self-ligating group it was observed that the frictional resistance was more with 0.020 inch wire than 0.017 x 0.025 inch wire (Table 1). This was contrary to the popular belief that round wires generate less friction than rectangular wires because round wires make a point contact with bracket slot whereas rectangular wire make line contact.[10] But this might not hold true for all situations.

In self-ligating brackets, when the clip is engaged it is in contact with the archwire and at non-binding angulations the contact area between the bracket slot and archwire is the important factor in friction. Whereas at greater angulation of the bracket the determining factor is, the point at which the wire contacts the edge of the bracket. So with round wires the bracket slot can "bite" into the wire at one point, causing an indentation in the wire.[28] Conversely, with rectangular wire the force is distributed over a larger area that is on the entire facio-lingual dimension of the wire resulting in decreased pressure and therefore lesser resistance to movement.[2]

Thus whether the clip is active or passive,friction depends on the size of the archwire relative to the size of the slot and also on the position of the archwire within the bracket.[23, 76, 86]

Tukey HSD test for Multiple Comparisons-when comparing individual self-ligating brackets and conventional brackets with 0.018-in stainless steel wire (Table 2) showed that the difference in frictional resistance between the different self-ligating brackets were not statistically significant (P>0.05).This was previously been stated by **Nigel Harradine**[28] that with thin round Stainless Steel wires upto 0.018 inches diameter, both the active and passive spring clips will be passive in nature and exerts minimum force on the archwire.

When comparing all bracket groups with 0.020 inch stainless steel wire (Table-3) no statistically significant difference in the values were seen between the Speed and the In-Ovation brackets (P>0.05) (Active group). This is in contrary to the findings of **Steven Budd et al** [80] who found difference in the frictional resistance between Speed and In-ovation brackets. Whereas all other groups showed statistically significant difference in frictional resistance (P<0.01).

With 0.017x 0.025 inch stainless steel wire all the brackets tested (Self ligating and conventional) showed highly significant levels of difference in frictional resistance (P<0.001) (Table 4), which was confirmed by the previous studies by **Luca Pizzoni.**[50]

Frictional resistance values with 0.019 x 0.025 inch and 0.021 x 0.025 inch wires revealed that Passive systems exhibited relatively lower values than Active systems but the difference among the two passive self -ligating systems

(Damon and SmartClip) were not statistically significant (P>0.05) (Table 5 & 6). This was in accordance with the study conducted by **Thorstenson GA & Kusy RP**[25] with 0.019 X 0.025 inch stainless steel wire who also reported lower frictional resistance values with passive systems.

Student T- test was done to compare Active systems, Passive systems and Conventional brackets between themselves and correspondingly with the other groups. Within the Passive self- ligation group, Damon brackets exhibited less frictional resistance than SmartClip for all the wire groups tested (Table 7). The mean difference in resistance between Damon and SmartClip was statistically significant for all wires (P<0.05) except for 0.018 inch Stainless Steel wire which was not statistically significant (P>0.05).

The Smartclip bracket consists of two NiTi clips that open and close through elastic deformation by which archwires are retained within the slot.[32] Whereas in Damon self-ligating brackets the labial slide which is designed to capture archwire in the slot is made of stainless steel. This may be attributed to the increase in frictional resistance with Smartclip than Damon brackets.[39]

Among the Active self-ligating group, (Table 8) In-Ovation showed less frictional resistance than Speed brackets for all the wires tested and the difference in the mean within this group was statistically significant (P<0.001) except for 0.020 inch wire (P>0.05). Similar finding was observed in the study conducted by **Steven Budd.**[80] The active clip of In-Ovation R brackets is made up of Cobalt Chromium alloy whereas the active clip of

Speed bracket is made up of Nickel Titanium. According to **Kapila et al**[39] and **Kusy et al,**[46] the surface roughness of Nickel Titanium is more than that of Cobalt Chromium alloy. This could be the possible reason for increase in frictional resistance with Speed brackets than In-Ovation R brackets.

When comparing Active versus Passive self-ligating systems, (Table 9) it was noticed that the passive systems showed comparatively lower frictional resistance than the Active systems for all the wires tested. The mean difference between the two systems were highly significant ($P<0.001$).

Passive slide of passive self-ligating brackets does not apply a ligating force to the archwire, whereas in Active self-ligating brackets; the active clip exerts an active force on the archwire which contributes to the increased frictional resistance towards sliding. Previous studies by **Harradine**[28] and **Thorstenson GA**[25] also revealed identical results.

Finally Conventional twin brackets showed high frictional resistance values when compared with both Active and passive self-ligating brackets (Table-10 & 11).[19,23,28,75] The difference in the frictional resistance between these two groups were also highly significant ($P<0.001$).

Among all the three bracket groups studied, Conventional twin brackets with elastomeric ligation showed highly significant increase in frictional resistance than both active and passive self-ligating brackets. This was in accordance with the studies conducted by **Edward Mah,**[21] **Harradine**[28] **& Simona Tecco.**[75]

Elastomeric ligatures are known to exhibit strain rate sensitivity, stress relaxation and poor strength.[76] In the present study the archwire bracket combination were tested within ten minutes of ligation with elastomeric modules so not much of force decay would have occurred. Hence the forces reported here in the present study might be the maximum expected.

Limitations of this study would be an interpretation of this in-vitro study to an in vivo situation. With any testing situation, it is impossible to reproduce the exact condition one might encounter in the oral environment like influence of saliva and other oral conditions such as malocclusion and masticatory action which can alter the mean resultant force between bracket and wire.[8,20,48] The effect of frictional resistance between bracket and archwire are also influenced by the other stages of orthodontic treatment like rotation correction, leveling and aligning, tipping and torqueing etc. Therefore the relative frictional forces obtained in this study are more meaningful when compared with each other as opposed to an actual force value that might be measured clinically on a patient.

Hence extensive clinical trials over long period are needed to evaluate the in-vivo effects of the frictional characteristics and relative torque expression of self-ligating brackets.

SUMMARY AND CONCLUSION

In this study we evaluated the frictional resistance of two Active and two Passive Self-ligating brackets and a Conventional twin bracket ligated with elastomeric module with five different dimension of stainless steel wires commonly used in orthodontic practice and to determine which among the two systems exhibit more kinetic frictional resistance.

Based on the statistical results derived from this study the following conclusions were drawn

a) Between Self-ligating and Conventional bracket systems, Self-ligating brackets offered less frictional resistance.

b) Passive bracket systems offer less frictional resistance than Active Self-ligating bracket systems and Damon brackets offered the least frictional resistance among all the brackets studied.

c) Damon Self-ligating brackets produced less frictional resistance then SmartClip brackets in the passive group and In-Ovation R produced less frictional resistance then Speed brackets in active group.

d) There was an increase in the frictional resistance as the wire dimensions increased. 0.018 inch round stainless steel wire showed the least friction while 0.021 x 0.025 inch rectangular stainless steel wires showed the maximum frictional resistance.

e) Conventional twin brackets with elastomeric ligatures which are still popular generate more friction than Self-ligating brackets.

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