ISSN: 2581-5989
PubMed - National Library of Medicine - ID: 101738774

International Journal of Dental Science and Innovative Research (IJDSIR)
IJDSIR : Dental Publication Service
Available Online at: www.ijdsir.com
Volume – 4, Issue – 4, July - 2021, Page No. : 399 - 406

Evaluation and Comparison of Frictional Resistance in Various Metal Passive Self-Ligating Bracket Systems: An In-Vitro Study

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Citation of this Article: Dr. Sohinderjit Singh, Dr. Amit Mehra, Dr. Shailaja Jain, Dr. Christy Nayyar, Dr. Jasleen Kaur, Dr. Avinab Mongra, "Evaluation and Comparison of Frictional Resistance in Various Metal Passive Self-Ligating Bracket Systems: An In-Vitro Study", IJDSIR- July - 2021, Vol. – 4, Issue - 4, P. No. 399 – 406.

Type of Publication: Original Research Article

Conflicts of Interest: Nil

Abstract

Objective: The aim of this study was to evaluate and compare the frictional resistance between various metal passive self-ligating brackets and 0.019×0.025 inches stainless steel archwire during sliding mechanics simulated on a Universal Testing Machine.

Materials and Method: Upper right canine passive metal self-ligating brackets of 0.022 × 0.028-inch slot dimension were used of following companies; Damon Q (Ormco, Orange, Calif); At-Ease (Modern Orthodontics, Ludhiana, India); Smart-Clip SL3(3M Unitek, Monrovia, California, USA); Empower 2 (American Orthodontics, Sheboygan) and Uni-Slide, United Dental Group. 20 brackets were evaluated from each of the mentioned five bracket systems. 100 arch-wire segments of stainless steel, 0.019×0.025-inch dimension of single brand was used. A total of 100 bracket-wire combinations were tested out at 0^0 angulations. The results were analyzed using Analysis of Variance (ANOVA) and further Post Hoc tests were done for further multiple comparisons between the five different bracket systems. The level of significance for the present study was fixed at 0.05.

Results: The Damon Q brackets had significantly the lowest mean frictional force[0.35N]. The highest mean frictional force was shown by UniSlide brackets [0.89N]. The other brackets were ranked as follows, from highest to lowest: SMARTCLIP SL3, AT EASE and EMPOWER 2.

Conclusion: The comparison of the mean frictional forces revealed that the lowest forces were found for Damon Q, At-ease and Smart Clip SL3 with the Damon Q bracket showing the least friction whereas Uni-slide showing the highest friction.

Keywords: Self-ligating brackets; Frictional resistance; Orthodontic brackets

Introduction

The human race has been rivetted with shifting teeth for a very long time with some form of 'Orthodontics' and tooth movement having been skilfully practiced for centuries.[1]

There are numerous systems that are being designed attempting to include the multi-technique therapy with the advantage and speed of self-ligation. Each bracket attempts to ‘borrow’ from all previously created systems and to improve the efficiency, size, aesthetic nature, ligation style and resistance requirements, all taking in consideration the required optimum orthodontic tooth movement.

Orthodontic tooth movement is a phenomenon requiring modifications in both biological and mechanical fields that result, in a controlled environment, in the desired movement of the tooth. This is reliant on the ability of the clinician to use ‘controlled’ mechanical forces to stimulate ‘biologic’ responses within the periodontium. It is important at this juncture to consider the numerous factors that may hamper or facilitate this tooth movement. Of prime importance, in this respect is the ‘frictional forces’ generated during orthodontic mechanotherapy.[2]

Friction is defined as a force that retards or resists the relative motion of two objects in contact. Therefore, a biologic tissue response with consequential tooth movement will occur only when the applied forces effectively overcomes the friction at the bracket-wire interface. Friction is only one part of which resistance to movement consists of when a bracket slides along an archwire. It is determined by the type and size of the archwire, type of bracket, angulation between the archwire and the bracket slot and the method of ligation.[3]

Since this force operates in the opposite direction of the mobile body, it is important that it be eliminated or minimized when orthodontic tooth movement is being planned, otherwise it may delay tooth movement, increase anchorage requirement, or both.[4] Friction is an uncontrolled variable of particular interest when continuous arch techniques are used to align and move teeth by way of sliding a tube or bracket along an archwire. Measuring this friction between the bracket and the arch wire has from long been a topic of interest for researchers as well.[5]

In 2011, Lorenz M. Brauchli et al compared friction of several self-ligating brackets with that of normal brackets and they concluded that the frictional resistance increases with increase in size of archwire and also that the passive self-ligating brackets were discerned with lower frictional resistance than the active self-ligating brackets.[6] Sennay Stefanos et al in 2010 evaluated the frictional resistance between active and passive self-ligating bracket and 0.019×0.025 inches arch wire, revealing that passive self-ligating brackets had both kinetic and static friction lower as compared to that of active self-ligating brackets.[7] Manu Krishnan et al in 2009, evaluated the frictional resistance between various different arch wire compositions of same size of 0.019×0.025 inches. They concluded that the friction was measured least when stainless steel archwire was used. They also concluded that when Nickel Titanium and Beta Titanium wires are to be used for guided tooth movement, passive appliances can minimize friction.[8] In summarizing the results of the various authors, there was agreement that the frictional resistance will increase with the following: wire size, angulations of wire to bracket and ligature force, and vary with a change in wire shape and a change in wire material. However, there are conflicting views on the influence of bracket width, lubrication, surface roughness and ligature design.

The following study aimed to evaluate frictional resistance between various arch wire combinations and the self-ligating brackets simulating oral environment by a water bath maintained at 37˚C using a thermostat. Previous studies attempted to evaluate the friction between self-ligating bracket systems but none of them were specifically restricted to India. Secondly, previous studies carried out the experiment in dry state thus not taking into consideration the effect of oral environment.

So, this study included various self-ligating brackets commercially available in India. It also discerned the bracket-archwire with the minimum friction in the wet state, thus trying to simulate the oral environmental conditions.

Materials And Methods

This was an *in vitro* study comprising of five different self-ligating bracket systems, which were evaluated for their frictional resistance with 0.019×0.025 inches rectangular archwire. Upper first quadrant canine brackets of MBT prescription, claiming to be of 0.022 × 0.028-inch slot dimension by their manufacturers were used. These were Damon Q (Ormco, Orange, Calif); At-Ease (Modern Orthodontics, Ludhiana, India); Smart Clip SL3 (3M Unitek, Monrovia, California, USA; Empower 2 (American Orthodontics, Sheboygan) and Uni-Slide, UDG (United Dental Group).

An experimental model was prepared by bonding brackets to an aluminum jig. The aluminum jig was prepared with precise dimensions of 20 × 30 × 20 mm. A line was scribed on the midline of each box parallel to the long axis of the box to act as a guide for reproducing the bonding position. Another line was scribed perpendicular to the above line. The bisecting point was taken as the midpoint of the jig ideal for placing the bracket. Individual brackets were bonded to each aluminium jig with bonding resin. (Fig. 1,2). Each bracket was bonded to single aluminium box to simulate tooth movement. A total of 100 jigs were manufactured for each bracket archwire combination.

The archwire sliding test was performed with a universal testing machine (Universal Testing Machine BANBROS, WDW 5 (Serial no. 20070802, Taiwan) (Fig. 3) connected to a 10KN load cell. This test was carried out at the Department of Mechanical Engineering, I.T.S. Engineering college; Greater Noida. In this study, a total of one hundred bracket-archwire samples were studied for evaluation of friction. A total of twenty brackets were evaluated from each of the mentioned five different bracket systems. Each bracket mounted on an aluminium jig was separately tested for the evaluation of frictional resistance. 100 arch-wire segments of stainless steel, 0.019×0.025-inch dimension of single brand were used. A total of 100 bracket-wire combinations were tested out at 00 angulation. Before testing, the bracket and archwire were kept in a water bath maintained at 37°C for 24hours to simulate oral environment and were then cleaned with 95% alcohol (Fig. 4) For the sliding test, the aluminium jig with the bracket-archwire combination, was attached to the base of Universal Testing Machine. Two lateral clamps were used to hold the apparatus in its position. The archwire was hooked at one end and through this hook, it was attached to the hook of the Universal Testing Machine (Fig. 5). The archwire was drawn through the bracket at a crosshead speed of 7 mm/min over a 10-mm stretch of archwire. The computer program was set to highlight the maximum frictional force during the initial movement. The peak values observed in force-distance graphs represented static friction force. (Fig. 6) A master file was made for frictional force value and data was statistically analyzed on a computer with the Statistical Package for Social Sciences(SPSS) software (version 22.0). The data were subjected to descriptive analysis for mean, mean difference, standard deviation, standard error, and significance of all variables. The results were analyzed using Analysis of Variance (ANOVA) and it was seen that there were statistically significant differences in frictional forces of different bracket systems. Therefore, Post Hoc tests were done for further multiple comparisons between the five different bracket systems. The level of significance for the present study was fixed at 0.05.

Results

The descriptive Statistical analysis revealed the mean frictional force values for DAMON Q (Ormco), SMARTCLIP SL3 (3M Unitek), AT EASE (Modern Orthodontics), EMPOWER 2 (American Orthodontist) and UniSlide (United Dental Group). (Table 1) The mean frictional force was lowest for DAMON Q (Ormco) whereas highest for UniSlide (UDG). (Graph 1) Further the multiple comparisons of all bracket systems with each other were made and results were tabulated in Table 2 to Table 6.

In Table 2, the frictional force of DAMON Q was compared with the other bracket systems to find the statistical significance. It was discerned that there was statistically significant difference ($p<0.001$) found on comparison of frictional force of DAMON Q with AT EASE, EMPOWER 2 and UniSlide. Lesser significance ($p<0.05$) was found on comparison with SMARTCLIP SL3.

On comparison of SMARTCLIP SL3 with other bracket systems in Table 3, a statistical significant difference ($p<0.001$) was found on comparison of frictional force with EMPOWER 2 and UniSlide Lesser significance (0.05) was found on comparison with AT EASE.

Table 4 represented the comparison of frictional force of AT EASE with other bracket systems to find the statistical significance. Statistical significant difference was seen found with DAMON Q, EMPOWER 2 and UniSlide.

Table 5 represented the comparison of frictional force of EMPOWER 2 with other bracket systems to find the statistical significance. Statistical significant difference was seen found with DAMON Q, SMARTCLIP SL3, AT EASE and UniSlide.

Discussion

The specialty of orthodontics has continued to develop since its advent in the early 20th century. Changes in treatment philosophy, mechanics, and appliances have helped shape our understanding of orthodontic tooth movement. The claim of reduced friction with self-ligating brackets is often cited as a primary advantage over conventional brackets.9-11 This occurs because the usual steel or elastomeric ligatures are not necessary, and it is claimed that passive designs generate even less friction than active ones.6,12 With reduced friction and hence less force needed to produce tooth movement, self-ligating brackets are proposed to have the potential advantages of producing more physiologically harmonious tooth movement by not overpowering the musculature and interrupting the periodontal vascular supply.10 Therefore, more alveolar bone generation, greater amounts of expansion, less proclination of anterior teeth, and less need for extractions are claimed to be possible. Other claimed advantages include full and secure wire ligation,13 better sliding mechanics and possible anchorage conservation,10,11 decreased treatment time, longer treatment intervals with fewer appointments, chair time savings, less chair-side assistance and improved ergonomics, better infection control, less patient discomfort, and improved oral hygiene.14-15 The specific aims of the present study were to evaluate the mean frictional forces of the five-different passive metal self-ligating bracket systems, during sliding movement of stainless steel archwire over the self-ligating bracket, with angulation of 0º between the bracket and the archwire and to compare the mean difference of the evaluated frictional force. This study also took into consideration the oral environment as a major factor in deciding the resultant frictional forces and therefore the study was performed on metal self-ligating brackets which were kept for 24 hours in a hot water bath maintained at 37ºC. One hundred metal passive self-ligating brackets, twenty brackets from each bracket system were tested for evaluation of frictional forces. The archwire sliding test was performed with a universal testing machine. A total of 100 bracket-wire combinations were carried out at 00 angulations. Our results with 0.019×0.025-inch stainless steel archwire revealed that the frictional force of DAMON Q(ORMCO) brackets was highly significantly ($p<0.001$) when compared with AT EASE (Modern Orthodontics), EMPOWER 2 (American Orthodontist) and Uni-Slide (United Dental Group) brackets and insignificant p-value($p=0.074$) was observed with SMARTCLIP SL3 (3 M, UNITEK) brackets indicating that the DAMON Q brackets showed a lesser frictional resistance in comparison to At Ease, Empower 2 and UDG brackets whereas the friction was of not much significance when compared with Smartclip SL3 brackets. (TABLE 2). Similarly, SMARTCLIP SL3 showed a highly significant ($p<0.001$) result when compared to EMPOWER 2 and UDG, whereas statistically insignificant result was obtained in comparison with DAMON Q and AT EASE. This indicated that EMPOWER 2 and Uni-Slide brackets displayed a significantly higher friction than SMARTCLIP SL3 whereas DAMON Q and AT EASE showed no significant difference with respect to SMARTCLIP SL3. (TABLE 3) In the present study, an Indian manufacturing company Modern Orthodontics showed highly significantly ($p<0.001$) results, when compared with DAMON Q, EMPOWER 2 and Uni-Slide and lesser significance($p<0.05$) was seen with SMARTCLIP SL3. This result indicated that At Ease showed lesser frictional resistance when compared with EMPOWER 2 and UDG but higher friction when compared with DAMON Q. Another important noticeable aspect was that the friction was not of much difference when it was compared with SMARTCLIP SL3. Hence, At ease bracket proved to be really effective in terms of reduced frictional resistance (TABLE 4). Similarly, comparing the results of EMPOWER 2 with other bracket systems it showed highly significantly ($p<0.001$) results, when compared with DAMON Q, SMARTCLIP SL3, Uni-Slide and lesser significance ($p<0.05$) was seen with At Ease indicating that, more friction was produced as compared with DAMON Q and SMARTCLIP SL3 followed by At Ease but also a lesser frictional resistance when in comparison with Uni-Slide. In our present study, we intended to compare the frictional forces of passive self-ligating designs with Stainless Steel archwire alloy. It is also reported that frictional resistance increases correspondingly with an increase in archwire size for self-ligating brackets. Thus, we evaluated friction in well-controlled, wet conditions with 0º angulation, using a larger archwire of 0.019 × 0.025 inch. An important aspect to consider when evaluating bracket design is the normal (perpendicular) force of ligation. In most studies, the frictional force decreases as the normal ligation force is minimized. Different methods of ligation that have been introduced with edgewise brackets have resulted in varying normal forces and their corresponding frictional forces. Frictional forces are important to study because a large, variable percentage of the force applied by the orthodontist is lost to overcome friction instead of moving teeth. Information about the friction of orthodontic brackets and archwire systems is important for improving the effectiveness of orthodontic treatment. The selection of brackets should be based on the desired clinical outcome. Low frictional forces might be desired during levelling and aligning but could be inappropriate for expressing the torque in the bracket or achieving other objectives of finishing and detailing. Likewise, high frictional forces might be desired for expressing torque in the bracket or finishing and detailing but be inappropriate for the levelling and aligning stages of treatment. In contemporary orthodontics, many practitioners utilize sliding mechanics for both closing extraction spaces and aligning irregular teeth. As this procedure requires the teeth to be displaced relative to the archwire, a portion of any force that is applied to move the teeth must be consumed by overcoming the inherent friction of the system. An understanding of the friction produced during sliding mechanics is critical for the clinicians. Merely increasing the force in an orthodontic appliance will not remedy high friction / archwire bracket couple, it will double the frictional force. Additionally, excessive amount of archwire/bracket friction may ultimately result in a loss of anchorage or in binding accompanied by little or no tooth movement.

Summary and conclusion

Within the limitations of this in-vitro study, the following conclusions were drawn that the comparison of the mean frictional forces of the different metal passive self-ligating brackets manufactured by five different bracket manufacturing companies, revealed that the lowest mean frictional forces were found for Damon Q (Ormco), At-ease (Modern Orthodontics) and Smart Clip SL3 (3M).

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Legend Table and Figure

Fig. 1: Jig prepared with bracket bonded

Fig. 2: Bracket archwire combination

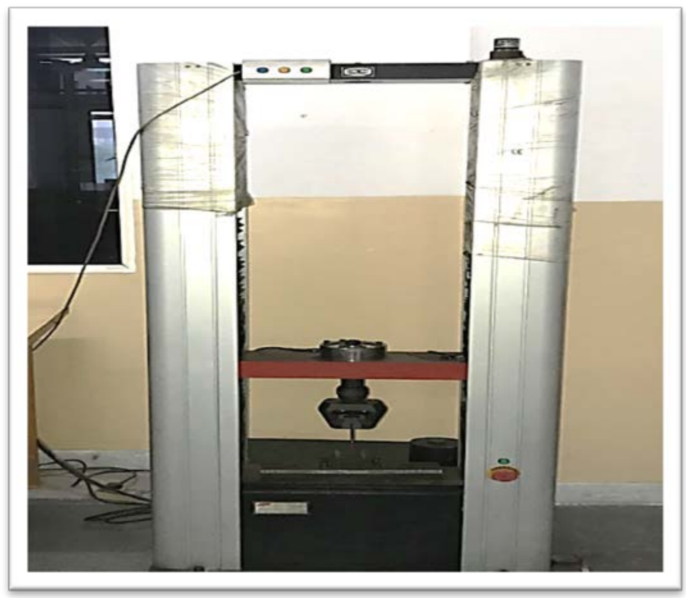


Fig 3: Universal Testing Machine BANBROS.

Fig. 4: water bath maintained at 37°C

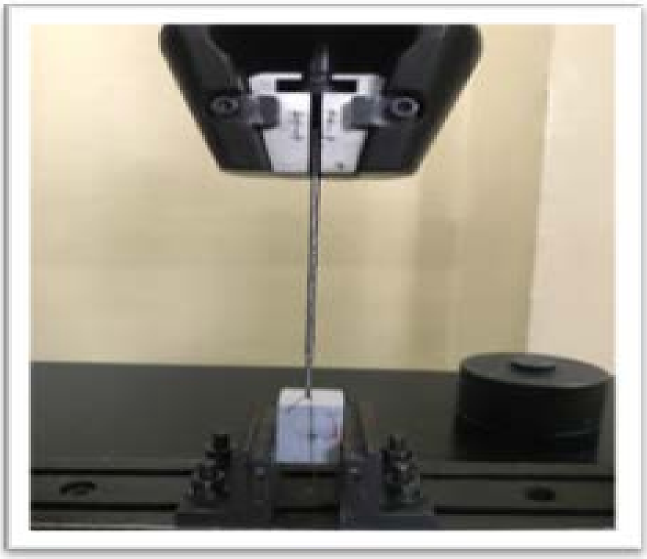


Fig. 5: Jig placed in the Universal testing machine

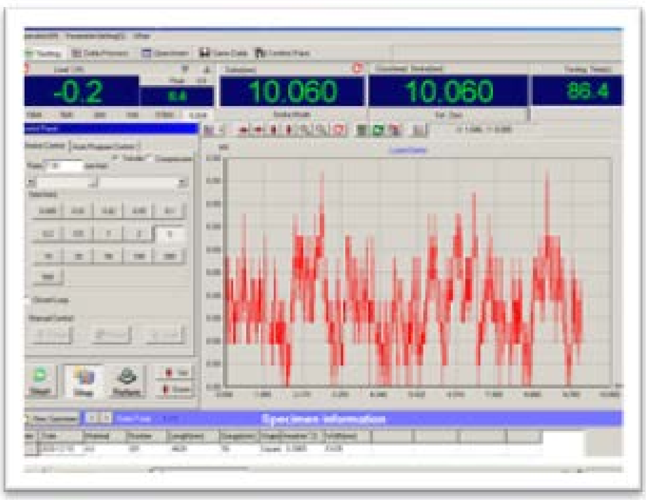


Fig. 6: Force-distance graph representing friction force

Bracket system	N	Frictional force (newtons)	
		Mean ± Std. Deviation	Std. Error
Damon q (ormco)	20	0.35 ± 0.0944	0.02111
At ease (modern orthodontics)	20	0.50 ± 0.0858	0.0191
Smart clip sl3 (3m unitek)	20	0.42 ± 0.0921	0.02127
Empower 2 (American orthodontist)	20	0.61 ± 0.0911	0.0203
Uni slide (united dental company)	20	0.89 ± 0.1089	0.0237

The mean difference is statistically significant at the <0.5* level and highly significant at <0.001** level.

Table 1: Mean Frictional Forces between 0.022-inch metal passive self-ligating stainless-steel brackets of various bracket manufacturers and 0.019×0.025inch Stainless Steel archwire

Damon q (orcmo)Vs	N	Frictional force (newtons)		
		Mean Differences	Std. Error	Sig. (p value)
Smart clip sl3	20	0.08	0.0295	.074
At ease	20	0.16	0.0285	.001*
Empower 2	20	0.27	0.0293	<0.001**
Uni slide	20	0.54	0.0322	<0.001**

Table 2: Comparison of mean frictional force of DAMON Q brackets (Ormco) with other bracket systems

Smart clip sl3 (3m unitek) Vs	N	Frictional force (newtons)		
		Mean Differences	Std. Error	Sig. (p value)
At ease	20	0.08	0.0281	0.071
Empower 2	20	0.19	0.029	<0.001**
Uni slide	20	0.47	0.0319	<0.001**

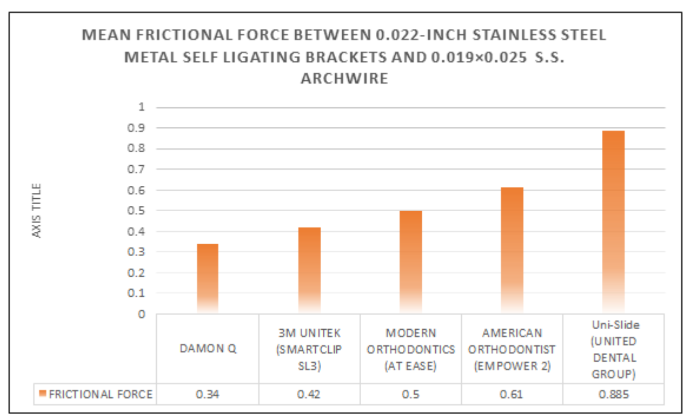
Table 3: Comparison of mean frictional force of SMARTCLIP SL3 (3M) brackets with other bracket systems

At Ease (Modern Orthodontics) Vs	N	Frictional Force		
		Mean Differences	Std. Error	Sig. (P Value)
Empower 2	20	0.11	0.028	0.004*
Uni Slide	20	0.39	0.031	<0.001**

Table 4: Comparison of mean frictional force of AT EASE (Modern Orthodontics) brackets with other bracket systems

Empower 2 (American orthodontist) vs	N	Frictional force (newtons)		
		Mean Differences	Std. Error	Sig.(p value)
Uni slide	20	0.28	0.0317	<0.001**

Table 5: Comparison of mean frictional force of EMPOWER 2 (American Orthodontics) brackets with other bracket systems.



Graph 1: Mean Frictional Force between 0.022-inch stainless steel metal passive self-ligating brackets and 0.019×0.025 S.S. archwire