The Study of Frictional Force in Self-Ligating Orthodontic Brackets

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***Abstract*—This study was conducted to evaluate the frictional force level among self-ligating ceramic brackets compared with conventional ceramic brackets, self-ligating stainless steel brackets, and conventional stainless steel brackets. Each tested bracket were mounted in passive ligation with the tested wire on the customized jig. Each bracket and wire (0.016 x 0.022" SS) combinations were tested under Universal Testing machine (Instron) with the sliding velocity of 1mm./min and a load cell of 50 newtons. All data were statistically analyzed by a Kruskal Wallis and a Mann Withney U tests. (p<0.05). The results showed significant difference in frictional force among all 4 types of brackets when they were compared to each other. The self-ligating metal brackets produced the lowest frictional force followed by self-ligating ceramic brackets, conventional metal brackets and conventional ceramic brackets, respectively. Therefore, self-ligating ceramic bracket is likely to be a good alternative appliance of choice to solve the problem of frictional force for those patients with esthetic concern during orthodontic treatment**

***Index Terms*—friction, self-ligating bracket, conventional bracket, ceramic bracket**

I. INTRODUCTION

Frictional force as defined by Rossouw is the force which acts upon the opposite direction of the desired movement and resist against the movement when one surface slide along the other [1]. In orthodontics, other problems associated with frictional force always encounter when sliding mechanics are used. In order for tooth to move, the frictional forces must be overcome. It was found that more than 60% of the applied force must be sacrificed for frictional resistance [2], [3]. This means that anchorage teeth receive more force than really required, leading to anchorage loss due to excessive force on anchorage unit (Echols *et al*., 1975). Moreover, a high frictional force can cause notching and binding of the arch wire and the bracket. Accordingly, inhibition of tooth movement may arise, resulting in a prolong treatment time, patients, discomfort during treatment, and damage of the orthodontic appliance.

Frictional force is affected by two major factors, biological and mechanical factor. For the bi-ological factors, saliva (Baker *et al*., 1987), plaque, and acquired pellicles can influence the resistance to tooth movement [4]. With respect to the latter one, mechanical factors, many factors influencing the friction are found. In 2013, Nucera *et al*. reported that the dimension of the slot and the slot edge affected the resistance to sliding [5]. Applied moment was also found to play a role in modifying the level of frictional force [6], [7]. Moreover, bracket materials [8], bracket designs [9]-[11], the surface roughness of brackets and arch wires [12], wear of the wire [13], arch wire size and material [14], [15], inter-bracket distances [16] and the method of ligation [17] are also identified as factors affecting the resistance to tooth movement as well.

To decrease the frictional force between bracket and arch wire, many attempts have been made including the development of new bracket design. Currently, self-ligating bracket becomes more popular as it was introduced as a low frictional force brackets. Thus it provides optimal force for tooth movement and decrease patient discomfort and treatment time [18], [19].

Since the number of adult undergoes orthodontic treatment is rising, there has been an increase in demand for aesthetic orthodontic appliances. The advents of ceramic brackets offer a way to meet this aspect of patients' expectation. Nevertheless, this is not unmixed blessing, despite their aesthetic appearance, one of the most important problems comes along with ceramic bracket is its frictional properties.

Lately, many studies have been attempted to compare the frictional force between conventional and self-ligating brackets. Many investigators evaluated the frictional force between metallic conventional and self-ligating bracket and concluded that the self-ligating metal bracket had a significant lower frictional forces compared to the conventional one [20]-[24]. One study investigated the frictional force among self-ligating ceramic brackets, metal slot ceramic self-ligating brackets and conventional ceramic brackets and found that both self ligating ceramic and metal slot ceramic bracket produced significant lower frictional force than conventional ceramic brackets [25].

II. MATERIAL AND METHODS

A. Materials

1) Brackets

Four types of brackets were used in this study. All of them have 0.018 x 0.025 inches slot with Roth prescription of an upper canine brackets with minus 2

Manuscript received March 26, 2016; revised June 14, 2017.

doi: 10.18178/ijmerr.6.4.290-295

degrees pre-torque and 9 degrees pre-angulation. The details of each types of brackets used in this study were shown in Table I.

TABLE I. DETAILS OF BRACKETS FROM AMERICAN ORTHODONTICS COMPANY USED IN THIS STUDY

Bracket	 Group 1 : Empower Clear	 Group 2 : 20/40™ Ceramic	 Group 3 : Empower metal	 Group 4 : Master
Material	Polycrystalline ceramic		Stainless steel	
Type of construc-tion	Ceramic injection molding		Metal injection molding	
Type of ligation	Interactive self ligation	Standard ligation	Interactive self ligation	Standard ligation

2) Wire

2.1.1 Stainless steel wires of 0.016 x 0.022 inches were used as tested wires.

2.1.2 Stainless steel wires of 0.018 x 0.025 inches were used as template wires.

3) Elastomeric modules

All elastic modules used in this experiment were in the same colour from American Orthodontics.

B. Sample Preperation

1. Each brackets was bonded to cylindrical acrylic block of radius whose radius and height were 2.5 cm.

2. The sample was then attached to the customized jig (Fig. 1) that had been fixed to the Universal Testing Machine (Instron 5567 Testing Machine).

3. The template wire was then used to adjust the bracket alignment at the jig to ensure that the wire lied flat in bracket slot.

4. After that the template wire was then replaced with the tested wire with care to eliminate the chance of introducing torsion. This ensured passive configuration between arch wire and bracket. The wire was held in slot clip for self-ligating bracket and with elastomeric module for conventional bracket right before friction testing to avoid the effect of relaxation.

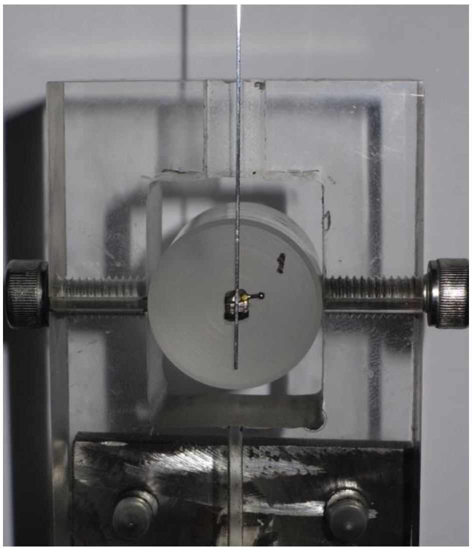

Figure 1. The customized jig fixed to the Universal Testing Machine (Instron 5567).

C. Frictional Testing

The frictional force was measured by the universal Instron 5567 testing machine with sliding velocity of 1 mm/min, and a load cell of 50 newtons. Each sample was measured once to eliminate the effect of wear on the frictional force. The wire was drawn along the bracket at the distance of 1mm to simulate the distance of tooth movement during canine retraction stage between monthly appointment. The maximum static friction of each samples represented by the peak of the graph was then automatically recorded in computer (Fig. 2). After that, the machine was stopped to remove the old sample and a new combination of bracket and wire was replaced. This study was done in dry condition to avoid contamination.

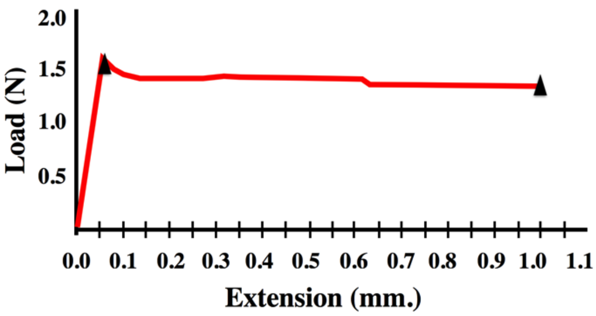

Figure 2. The graph demonstrated the result from Instron machine of one sample with the peak of the graph represented static frictional force.

D. Statistical Analysis

A Kruskal-Wallis test and a Mann-Whitney *U* test for the post hoc test were used to analyze the result to evaluate whether there was significant difference in frictional force among different ligation methods and material of brackets. The level of significance for all the tests was set at $p < 0.05$. All statistical analyses were performed with IBM SPSS statistic 20 software.

III. RESULTS

The means frictional force were shown in Table II. From the table, static frictional force of AO self-ligating metal brackets were the lowest followed by that of AO self-ligating ceramic, AO conventional metal and AO conventional ceramic brackets, respectively. The statistical analysis showed all groups were significant difference when compared to one another (p <0.05).

IV. Discussion

Orthodontic treatment is based primarily on the force delivered to teeth and supporting structures, which lead to bone resorption and deposition thereby allowing teeth to move in the desired direction. However, frictional force usually occurs when teeth move along the arch wire. Nanda et al. pointed out that both biological and physical factors can influence the amount of frictional force.

TABLE II. Details of Brackets from American Orthodontics Company used in This Study

Group	N	Mean	SD.
1.AO conventional metal	15	1.0412	0.034241
2.AO self-ligating metal	15	0.2365	0.010531
3.AO conventional ceramic	15	1.6799	0.036116
4.AO self-ligating ceramic	15	0.4012	0.015045

Physical factors such as different materials, surface characteristics, mechanical properties of the wire and bracket as well as the method of ligation play a vital role in determining the level of frictional force [4].

Presently, patients have more concerns on esthetic appearance, accordingly there have been an increase in demands for esthetic brackets. Many kinds of material have been introduced for this purpose including ceramic brackets. However, in spite of their esthetic appearance, ceramic brackets have the disadvantages that they are brittle and their tie wing may become fractured during treatment. Their extreme hardness is also a problem because this can cause enamel wear of occluding teeth. Problems during debonding also pose another obstacle. Furthermore, it has been shown by many studies that ceramic brackets create higher frictional force than that of metal brackets [8], [10]. Pertaining to the result in this study, self-ligating metal brackets produced significant lower frictional force than self-ligating ceramic brackets. These results are in accordance with those reported by Lee et al. which indicated that the combination of stainless steel wire of 0.019 x 0.025 inches and polycrystalline ceramic self-ligating ceramic brackets produced a higher frictional force than that of self-ligating metal brackets [26]. In addition, the results in this study also showed that conventional metal brackets yield a significant lower amount of frictional force compared with that of conventional ceramic brackets which are in agreement with the results from the studies conducted by Angolka et al., and Cacciafesta *et al*. [8], [27]. Therefore, these results further support the claim that bracket material is one of the factors determining frictional force level. Choi et al. pointed out that ceramic brackets produced a higher amount of friction because of their greater surface roughness and porosities when compared to the smoother surface of metal brackets [28]. Nevertheless, the mean frictional force found in this study was lower than that reported from previous studies. Choi *et al*. demonstrated the mean frictional force of 0.48 N and 1.015 for self-ligating metal and self-ligating ceramic, respectively. Cacciafesta *et al* also indicated a higher mean frictional force for conventional metal (2.79 N) and ceramic brackets (3.41 N). These disparities are owing to the difference in size of the wire used in the experiments. In our study, stainless steel wires of 0.016 x 0.022 inches, which are the commonly used during retraction phase were used as the tested wire whereas wires of 0.019 x 0.025 inches were used for the other two studies. With reference to Omana *et al*., the lager size of wire will fill the slot, resulting in a decrease of slot play and greater normal force. As a result, a higher amount of frictional forces were generated [29].

Apart from the roughness of the ceramic, Profitt also noted that the greater hardness and inflexibility of ceramic brackets may be other factors responsible for higher level of frictional force because they are prone to producing more damage to the arch wire, namely notching which can increase resistance to tooth movement [30]. For the aforementioned reasons, it can be expected that self-ligating ceramic brackets would also produce higher frictional force than conventional metal brackets. However, the results of this study show that this is not the case. Lower frictional forces were found for self-ligating ceramic brackets compared with that of conventional metal brackets which are consistent with that reported by William et al. According to their results, self-ligating ceramic brackets generated significant lower frictional force (2.92 N) than conventional metal brackets (3.63 N). Nonetheless, the mean frictional force reported in their study was greater than that exhibited in this study. This is again because of the larger size of wire of 0.018 x 0.025 inches that they used. Moreover, in the study conducted by William et al., each bracket was tested ten times whereas in this study, each brackets was tested only once to eliminate the effect of wear on frictional force [25]. Kapur *et al*. indicated that the repeated use of brackets would result in greater surface roughness as a result of abrasive wear, eventually resulting in a higher amount frictional force. They also suggested that for proper evaluation of frictional force, each sample should be tested only once. The reason behind the lower frictional force found in self-ligating ceramic brackets compared to that of conventional metal brackets can be attributed to an improvement in the quality of surface polishing of the slot and also the development in manufacturing process which allows the ceramic bracket to be fabricated by an injection molding process like that of a metal bracket. Thereby, these factors help reducing surface roughness and imperfections usually arising from the cutting process of the old milling technique. Furthermore, the ligation method can also account for the lower level of frictional force of self-ligating ceramic brackets [26].

The ligation method has an effect on frictional force through the normal force (N), the force pushing two surfaces together. According to the static friction formula, $F=\mu N$, it can be seen that the greater the amount of normal force, the more frictional force will be increased. The amount of normal force can range from 50-700 grams depending on the ligation method as reported by

Nanda. Many studies suggested that self-ligating brackets produce a lower frictional force than conventional brackets because their inherent door created a lower normal force compared to standard ligation of conventional brackets [8]-[10]. The results from this study demonstrate that metal self-ligating brackets produce a lower frictional force than conventional metal brackets. Similarly, ceramic self-ligating brackets also yield a significantly lower frictional force than conventional ceramic brackets. This result is also consistent with the results from previous studies [25], [26], [31]. One study manifested that self-ligating metal brackets introduced significantly lower frictional force than conventional metal brackets. Howbeit, the mean frictional force of 1.01 and 3.17 for self-ligating and conventional bracket, were respectively higher than those found in this study. Again the larger size of wire of 0.017 x 0.025 inches could be held responsible for this disparity. In addition, two brackets were tested each time whereas only one bracket was used in this study. The larger net surface contact area explains the greater frictional force found in their study. The results from this study and as well as those of previous studies lend further credence to the claim that the method of ligation does have an influence on the level of frictional force. Berger stated that the self-ligating bracket, as implied in their name, has the ability to hold the wire by itself with the built in door that turns the bracket into tube. Therefore, the arch wire is held loosely within the slot [32]. Contradictorily, in conventional brackets, Berger and Shivapuja *et al*. reported that elastomeric modules or stainless steel ligatures that are used to hold arch wires within slots will exert a relatively higher force and ultimately press the arch wire more tightly against the slot of bracket compared to that of self-ligating brackets. Therefore, they suggested that the method of ligation could contribute to a lower frictional force produced by self-ligating brackets [32], [33]. In addition, Shivapuja *et al*. also noted that surface roughness of the ligation materials could be another factor accounting for frictional force. According to their study, the teflon-coated elastomeric module produced the lowest frictional force compared to conventional elastomeric ligatures. This finding could be attributed to the relative smoother surface of the teflon-coated elastomeric ligature that helps reducing the mechanical binding of elastomeric ligature to the surface of the wire [33]. Hain et al. also conducted a study to compare frictional force among conventional brackets with the new slick elastomeric modules from TP Orthodontics (La Porte, Ind), conventional brackets combined with conventional modules, and SPEED self-ligating brackets. The results showed that SPEED self-ligating brackets create the lowest level of frictional force followed by Slick module and conventional module, respectively. The authors indicated that the metal door of self-ligating brackets have a smoother surface than that of slick elastomeric module and conventional module, respectively, thereby producing the lowest frictional force among all [34]. In summary, the results of this research showed that self-ligating metal brackets produce the least amount of frictional force followed by self-ligating ceramic brackets, conventional metal brackets, and conventional ceramic bracket, respectively. It can be concluded that components such as the method of ligation, surface roughness of ligation material, surface roughness of the bracket material, as well as hardness of the material have an influence on amount of frictional force. Regarding the effect of wear, there has been only one study that compared the effect of wear on frictional force between non-repeated and repeated use of brackets and found that wear and frictional force do increase with repeated use. However, only stainless steel and titanium brackets were included in their study [13]. Therefore, further studies are required to clarify whether there are any differences in the wear pattern between ceramic and metal brackets with repeated use and also the influence of wear on the level of frictional force. After all, the result in this study can provide useful information when decision has to be made in term of selection of type and material of bracket for individual patient.

V. Conclusion

1. Self-ligating metal brackets produce the lowest frictional force followed by self-ligating ceramic, conventional metal and conventional ceramic brackets, respectively.
2. Considering the mode of ligation, the results demonstrated that self-ligating metal and ceramic brackets produce significantly lower frictional force than conventional metal brackets conventional ceramic bracket, respectively.
3. Concerning the bracket material, self-ligating metal conventional metal brackets yield significantly lower frictional force compared to self-ligating ceramic and conventional ceramic brackets, respectively.

Acknowledgment

I would like to thank Lecturer Nuntinee Nanthavanich Saengfai, Lecturer Rochaya Chintavalakorn, Assistant professor Dr.Poompada Joachakarasiri, and Dr. Kongkwan Mekaapirak for their constant support and guidance throughout this project.

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