การเปรียบเทียบความต้านทานเสียดทานที่เกิดจากแบร็กเกตชนิดมัดในตัวและแบร็กเกตมาตรฐานที่มัดด้วยตัวมัดหลายแบบ

Comparison of Frictional Resistance Produced by Self-ligating Brackets and Conventional Brackets Ligated with Various Types of Ligature

จิรวรรณ ชาติพิทักษ์[1], ณัฐวิทย์ พรหมมา[2], ธีระวัฒน์ โชติกเสถียร[3], จรรยา อภิสริยะกุล[3], วิกันดา เขมาลีลากุล[3]
[1]นักศึกษาระดับบัณฑิตศึกษา สาขาวิชาทันตกรรมจัดฟัน คณะทันตแพทยศาสตร์ มหาวิทยาลัยเชียงใหม่
[2]ภาควิชาวิศวกรรมเครื่องกล คณะวิศวกรรมศาสตร์ มหาวิทยาลัยเชียงใหม่
[3]ภาควิชาทันตกรรมจัดฟันและทันตกรรมสำหรับเด็ก คณะทันตแพทยศาสตร์ มหาวิทยาลัยเชียงใหม่
Jirawan Chartpitak[1], Nattawit Promma[2], Dhirawat Jotikasthira[3], Janya Apisariyakul[3], Wikanda Khemaleelakul[3]
[1]Graduate student, Division of Orthodontics, Department of Orthodontic and Pediatric Dentistry, Faculty of Dentistry, Chiang Mai University
[2]Department of Mechanical Engineering, Faculty of Engineering, Chiang Mai University
[3]Department of Orthodontics and Pediatric Dentistry, Faculty of Dentistry, Chiang Mai University

ชม. ทันตสาร 2562; 40(2) : 39-50
CM Dent J 2019; 40(2) : 39-50

Received: 5 April, 2018
Revised: 15 May, 2018
Accepted: 16 May, 2018

บทคัดย่อ

การศึกษานี้มีวัตถุประสงค์เพื่อเปรียบเทียบความต้านทานเสียดทานที่เกิดจากแบร็กเกตชนิดมัดในตัว และแบร็กเกตแบบมาตรฐานที่มัดด้วยตัวมัด 5 แบบ มัดลวดเหล็กกล้าไร้สนิมแบบเส้นตรงขนาด 0.021×0.025 นิ้ว เข้ากับแบร็กเกตซี่ฟันกรามน้อยบนที่มีร่องแบร็กเกตขนาด 0.022 นิ้ว และใช้การมัดลวดเป็น 6 วิธี โดยมี 10 ตัวอย่างต่อหนึ่งกลุ่มทดลอง ในกลุ่มทดลองที่ 1 ถึง 5 ใช้แบร็กเกตมาตรฐานที่มัดด้วยตัวมัดลวด 5 ชนิด คือ 1) ลวดเหล็กกล้าไร้สนิม ขนาด 0.010 นิ้ว 2) ยางมัดลวดมาตรฐาน 3) ยางมัดลวดเคลือบพอลิเมอร์ 4) ยางมัดลวดแรงเสียด

Abstract

The aim of the study was to compare frictional resistance among self-ligating brackets and the conventional brackets ligated with five types of ligature. 0.021×0.025-inch straight stainless steel (SS) wire were ligated on maxillary premolar brackets with 0.022-inch slots using six types of ligation method, 10 samples for each group. Five types of ligature: 1) 0.010-inch SS ligatures, 2) conventional elastomeric ligatures, 3) polymeric-coated elastomeric ligatures, 4) low-friction

Corresponding Author:

วิกันดา เขมาลีลากุล
ผู้ช่วยศาสตราจารย์, ภาควิชาทันตกรรมจัดฟันและทันตกรรมสำหรับเด็ก คณะทันตแพทยศาสตร์ มหาวิทยาลัยเชียงใหม่ 50200

Wikanda Khemaleelakul
Assistant Professor, Department of Orthodontic and Pediatric Dentistry, Faculty of Dentistry, Chiang Mai University, Chiang Mai 50200, Thailand
*E-mail: **wikandaw@hotmail.com***

ทานน้อย และ 5) ตัวมัดลวดแรงเสียดทานน้อย ตามลำดับ ส่วนกลุ่มที่ 6 ใช้แบร็กเกตเหล็กกล้าไร้สนิมชนิดมัดในตัวแบบไร้แรง วัดค่าแรงเสียดทานโดยใช้เครื่องทดสอบวัสดุอเนกประสงค์ นำข้อมูลมาวิเคราะห์ทางสถิติด้วยการจำแนกความแปรปรวนทางเดียว และเปรียบเทียบเชิงซ้อนด้วยสถิติชนิดดันเนต ที่มีนัยสำคัญน้อยกว่า 0.05

ผลการวิจัยพบว่ายางมัดลวดเคลือบพอลิเมอร์ทำให้เกิดแรงเสียดทานมากสุด ส่วนตัวมัดลวดแรงเสียดทานน้อยเกิดแรงเสียดทานน้อยที่สุด และไม่พบความแตกต่างอย่างมีนัยสำคัญเมื่อเปรียบเทียบกับลวดเหล็กกล้าไร้สนิม ยางมัดลวดแรงเสียดทานน้อยและแบร็กเกตชนิดมัดในตัว แต่พบว่าแรงเสียดทานมีค่าน้อยกว่าแรงเสียดทานที่เกิดจากยางมัดลวดมาตรฐานและยางมัดลวดเคลือบพอลิเมอร์อย่างมีนัยสำคัญ

สรุปได้ว่าตัวมัดลวดที่ออกแบบให้เป็นท่อได้แก่ ยางมัดลวดแรงเสียดทานน้อย ตัวมัดลวดแรงเสียดทานน้อยและแบร็กเกตชนิดมัดในตัว ทำให้เกิดแรงเสียดทานน้อยกว่ายางมัดลวดมาตรฐานและยางมัดลวดเคลือบพอลิเมอร์

คำสำคัญ: แรงเสียดทานทางทันตกรรมจัดฟัน ตัวมัด แบร็กเกต

elastomeric ligatures, and 5) low-friction clip ligatures were ligated on standard SS brackets in Groups 1 to 5, respectively. SS passive self-ligating brackets were used in Group 6. The frictional resistance of each sample was measured using a universal testing machine. The data were analyzed using the One-way ANOVA test followed by Dunnett's post-hoc test ($p<0.05$).

Polymeric-coated elastomeric ligatures produced the greatest frictional resistance. Low-friction clip ligatures produced the least frictional resistance and was not significantly different from that produced by SS ligatures, low-friction elastomeric ligatures, or self-ligating brackets, but was significantly less than that of conventional elastomeric ligatures or polymeric-coated elastomeric ligatures.

In conclusion, the tube-like designs (the low-friction elastomeric ligature, the low-friction clip ligature, and the self-ligating bracket) produced less frictional resistance than did the conventional and polymeric-coated elastomeric ligature.

Keywords: orthodontic friction, ligature, bracket

Introduction

Frictional resistance is the force resisting the relative motion that occurs between two surfaces sliding against each other.[1,2] The direction of frictional resistance is opposite to the direction of the movement. Frictional force is directly proportional to the normal force; perpendicular to the contacting surfaces, such that $F = \mu N$ (F = frictional force, μ = coefficient of friction, N = normal force). The coefficient of friction can be altered, depending on many factors, such as the material type of the object, surface hardness, surface chemistry and surface roughness.[1] Frictional resistance is classified as either static friction or kinetic friction.[3] Static friction is the force that resists the motion of a stationary object; the amount of the static force depends on the force applied to a non-moving object (the greater the force – the greater the static friction). The amount of force necessary to initiate movement of a static object is equal to the maximum static friction. Maximum static friction occurs before movement of the object, and is overridden after movement of the object begins. From this point, resistance to movement of the object is called kinetic friction. Theoretically, kinetic friction is less than static friction. However, orthodontic tooth movement is not a continuous event; it takes place in very short bursts and at slow speed.[4,5] Orthodontics tooth movement occurs at approximately 1 mm per month, or 0.23×10^{-4} mm per minute, making the process closer to a scenario in which static friction is more relevant.[6]

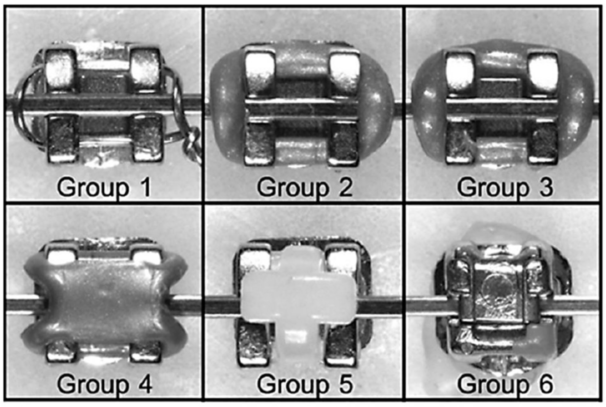
Frictional resistance in orthodontic treatment with fixed appliances is an important factor considered by the orthodontist because 12 - 60% of the applied force is dissipated due to frictional resistance.[1] During tooth movement, frictional resistance occurs at surface contacts among wire, bracket slot, and ligature.[7] A ligation method is a factor related to static frictional resistances that contributing to increased frictional resistance.[1] Applying too much force due to high frictional resistance would unnecessarily damage the periodontal tissue and would be unnecessarily stressful to the anchorage tooth, resulting in undesirable side effects, such as root resorption, unwanted tooth movement, loss of anchorage, as well as patient's discomfort.[8] Thus, the frictional resistance should be as low as possible for the best efficiency to move the tooth without loss of anchorage or damage to the periodontal tissue.

Recently, many innovative ligation systems have been developed for frictional resistance reduction, such as polymeric-coated elastomeric ligatures: Super Slick Mini Stix (TP Orthodontics Inc., La Porte, IN, USA)[9], low-friction elastomeric ligatures: Slide (Leone S.p.A., Sesto Fiorentino, Italy)[10], low-friction clip ligatures: Clear Snap (Densply Sankin Inc., Tokyo, Japan)[11] including self-ligating brackets. Many studies[9-23] have found that these ligatures and self-ligating brackets can reduce frictional resistance and some of them[11] can reduce the duration of canine retraction compared with stainless steel ligatures ligated on conventional stainless steel brackets. However, there does not have any investigation comparing the frictional property of all those innovative ligation systems to conventional ligation system. Therefore, the objective of this study is to compare the maximum static frictional resistance among the conventional stainless steel brackets ligated with five types of ligature (stainless steel ligatures, conventional elastomeric ligatures, polymeric-coated elastomeric ligatures, low-friction elastomeric ligatures and low-friction clip ligatures) and stainless steel passive self-ligating brackets ligated with its SpinTek slide, using sliding mechanics.

Materials and methods

The samples were divided into six groups according to the types of ligation method: 10 samples of each group (Table 1). In group 1 to 5, the standard SS brackets (Metal bracket, Dentsply Sankin Inc., Tokyo, Japan) with 0.022×0.028-inch slots having 0° torque, 0° tip and 0° rotation, which have a mesio-distal width of 0.115 inch, or 2.92 mm, were ligated with 5 types of ligature, which were 0.010-inch SS ligatures (Preformed Lig Ties Shorty, Ortho Technology, Florida, USA), conventional elastomeric ligatures (Standard Mini Stix – silver grey color: TP Orthodontics Inc., Indiana, USA) which have an outside diameter of 3.17 mm, an inner diameter of 1.13 mm, and a thickness of 1.02 mm, polymeric-coated elastomeric ligatures (Super Slick Mini Stix, TP Orthodontics Inc., Indiana, USA) which have an outside diameter of 3.17 mm, an inner diameter of 1.13 mm, and a thickness of 1.02 mm, low-friction elastomeric ligatures (Slide, Leone S.p.A., Sesto Fiorentino, Italy) medium module which have a width of 3.65 mm, a height of 4.05 mm, and a thickness of 0.56 mm, and low-friction clip ligatures (Clear Snap, Densply Sankin Inc., Tokyo, Japan), which have a mesio-distal width of 0.1147 inch, or 2.91 mm. In group 6, the SS passive self-ligating brackets (Damon Q, Ormco Corporation, California, USA) with 0.022×0.028-inch slots having -11° torque, +2° tip, 0° rotation, and a mesio-distal width of 0.110 inch, or 2.79 mm, were used. A 0.021×0.025-inch straight stainless steel wire (Ormco Corporation, Orange, California, USA) was placed in the bracket slot of each sample. The experimental models were shown in Figure 1.

In order to perform the frictional resistance testing models, the wire holder was attached to the superior clamp and the acrylic base holder was attached to the inferior clamp of the universal testing machine (Instron model 5566, Instron Industrial Products, Minnesota, USA) (Figure 2a). The wire was inserted into the wire holder. Then, the acrylic base was inserted into the acrylic base holder. The bracket was bonded on the acrylic base using Transbond XT Light Cure Adhesive system (3M Unitek, Monrovia, California, USA) in the position where the wire was passively seated into the bracket slot (Figure 2b). In order to polymerize the adhesive, the light cure unit (Mini LEDTM) (Satelec, Acteon, Mount Laurel, New Jersey, USA) provided light, which was applied to the bracket from four directions (Upper-Left, Upper-Right, Lower-Left, and Lower-Right) for ten seconds in each direction. In group 1 to 5, the light cure unit was applied before ligation of each groups. Whereas, in group 6, the SS passive self-ligating bracket was placed and adjusted on the acrylic base until the holding wire was seated into the bracket slot. Then, the SpinTek slide of the self-ligating brackets was closed. After that, the light cure unit was applied. Because of having the



รูปที่ 1 *รูปแสดงกลุ่มทดลองทั้ง 6 กลุ่มที่แบ่งกลุ่มตามชนิดของวิธีการมัดลวด*

Figure 1 *The experimental models of six testing groups divided according to the types of ligation methods.*

ตารางที่ 1 *กลุ่มทดลอง*

Table 1 *The sample groups.*

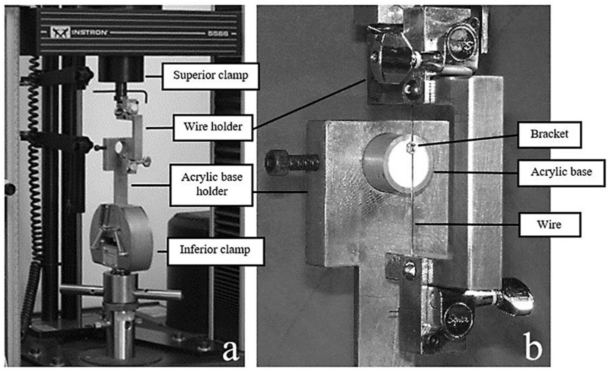
Group	Bracket type	Ligature	N
1	Conventional SS bracket (Metal BKT)	Stainless steel ligature (Preformed Lig Ties Shorty)	10
2	Conventional SS bracket (Metal BKT)	Conventional elastomeric ligature (Standard Mini Stix)	10
3	Conventional SS bracket (Metal BKT)	Polymeric-coated elastomeric ligature (Super Slick Mini Stix)	10
4	Conventional SS bracket (Metal BKT)	Low-friction elastomeric ligature (Slide)	10
5	Conventional SS bracket (Metal BKT)	Low-friction clip ligature (Clear Snap)	10
6	SS passive self-ligating bracket (Damon Q BKT)	-	10

tip, torque, and rotation of the passive self-ligating bracket slot, applied the light cure unit after ligation with its SpinTek slide was done for ensured that the wire was passive in bracket slot.

The static frictional resistance value of each sample was measured using experimental model mounted on the crosshead of the universal testing machine with a 100 N load cell, while 10 mm of wire was drawn vertically through the brackets at a speed of 10 mm/min in wet state; a drop of artificial saliva was applied on the ligated bracket before the experiment was performed. All experiments were performed by one examiner. The artificial saliva was manufactured by the Faculty of Pharmacy, Chiang Mai University. The composition of the artificial saliva, as proposed by Fusayama in 1963[24] was as follows:

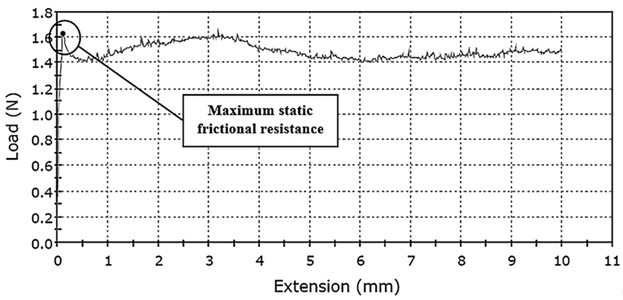
Sodium chloride (NaCl)	0.400	g/l
Potassium chloride (KCl)	0.400	g/l
Calcium chloride (monohydrate) ($CaCl_2 \cdot H_2O$)	0.906	g/l
Monosodium phosphate (dihydrate) ($NaH_2PO_4 \cdot 2H_2O$)	0.690	g/l
Sodium sulfide (monohydrate) ($Na_2S_9H_2O$)	0.005	g/l
Urea	1	g/l
pH	7.1	

The data was recorded on an X-Y recorder. The X–axis represents the extension of the wire beyond the bracket in millimeters and the Y–axis represents the resistance to the crosshead movement in Newton. The maximum static frictional resistance was indicated from the load-extension graph as a first highest load value before a continuous decrease (Figure 3). The maximum static frictional resistance was directly recorded in Newton and converted into gram.



รูปที่ 2 (a) รูปแสดงการจัดเตรียมตัวยึดลวดและตัวยึดฐานอะคริลิกบนเครื่องทดสอบ (b) รูปแสดงการจัดเตรียมลวดใส่ในตัวยึดลวดและแบร็กเกตวางบนตัวยึดฐานอะคริลิก

Figure 2 *(a) Setting of the wire holder and acrylic base holder on the universal testing machine. (b) Setting of the wire in the wire holder and the bracket on the acrylic base.*



รูปที่ 3 กราฟแสดงการกำหนดจุดแรงเสียดทานสถิตสูงสุด

Figure 3 *Graft indicating a specific maximum static frictional resistance.*

Statistical analysis

Due to normal distribution of the frictional resistance force value generated by the various orthodontic ligation methods. Differences in means of the maximum static frictional resistance among the testing groups were determined using the One-way ANOVA test followed by Dunnett's post-hoc comparison ($p < 0.05$). The data were analyzed using the Statistical Package for Social Sciences program version 17 for Windows (SPSS Inc., Chicago, Illinois, USA).

ตารางที่ 2 *แสดงค่าเฉลี่ย ค่าความเบี่ยงเบนมาตรฐานและค่าพิสัยของค่าแรงเสียดทานสถิตสูงสุดที่เกิดจากแบร็กเกตมาตรฐานที่มัดด้วยตัวมัด 5 ชนิดและแบร็กเกตชนิดมัดในตัว 1 ชนิด*

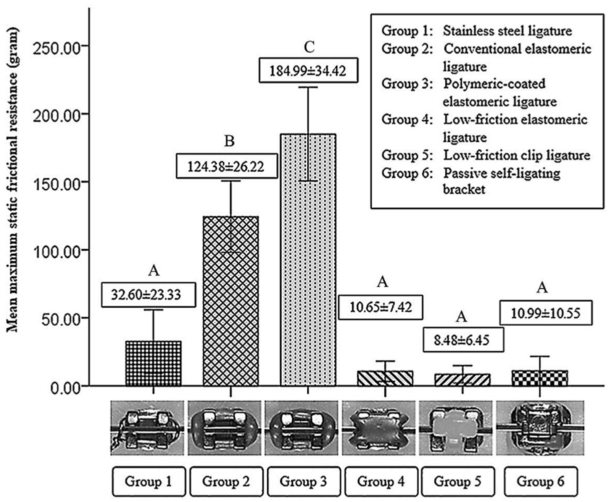
Table 2 *Mean, standard deviation and ranges of the maximum static frictional resistance values produced by conventional brackets ligated with five types of ligature and one type of stainless steel passive self-ligating brackets.*

Group	Maximum static frictional resistance (gram)			
	Mean	SD	Range	
			Max	Min
1: Stainless steel ligature (Preformed Lig Ties Shorty)	32.60^{A}	23.33	86.59	8.49
2: Conventional elastomeric ligature (Standard Mini Stix)	124.38^{B}	26.22	165.19	90.36
3: Polymeric-coated elastomeric ligature (Super Slick Mini Stix)	184.99^{C}	34.42	257.18	148.18
4: Low-friction elastomeric ligature (Slide ligature)	10.65^{A}	7.42	20.78	0.87
5: Low-friction clip ligature (Clear Snap)	8.48^{A}	6.45	17.71	0.95
6: Passive self-ligating bracket (Damon Q)	10.99^{A}	10.55	25.55	0.13

The group with A superscript indicate no statistically significant difference among the group with $p<0.05$
The group with A and B superscript indicate statistically significant difference between the group with $p<0.001$
The group with A and C superscript indicate statistically significant difference between the group with $p<0.001$
The group with B and C superscript indicate statistically significant difference between the group with $p<0.05$

Results

The descriptive statistics of the mean maximum static frictional resistance in each group are shown in Table 2. The conventional SS brackets ligated with a low-friction clip ligature (Group 5) provided the lowest mean maximum static frictional resistance. However, it was not significantly different from the SS ligature (Group 1), a low-friction elastomeric ligature (Group 4), and a SS passive self-ligating bracket (Group 6) (Figure 4). Among three elastomeric ligatures (Group 2, 3, and 4), the mean maximum static frictional resistance of the low-friction elastomeric ligature (Group 4) was significantly less than that of a conventional elastomeric ligature (Group 2) and the polymeric-coated elastomeric ligature (Group 3) ($p<0.05$). Besides, the mean static frictional resistance of the polymeric-coated elastomeric ligature (Group 3) was significantly greater than that of the conventional elastomeric ligature (Group 2) ($p<0.05$), as shown in Figure 4.



รูปที่ 4 *กราฟแสดงความแตกต่างระหว่างกลุ่มของค่าเฉลี่ยแรงเสียดทานสถิตสูงสุด แนวแกน Y แสดงค่าเฉลี่ยแรงเสียดทานสถิตสูงสุด ส่วนแนวแกน X แสดงกลุ่มการมัดลวดแต่ละชนิด*

Figure 4 *The graph show the difference of means maximum static frictional resistance with significant differences among the groups. Y-axis indicates the mean of the maximum static frictional resistance; X-axis indicates groups of ligation methods.*

Discussion

Three of the innovative ligation systems in this study, the low-friction elastomeric ligature, the low-friction clip ligature, the SS passive self-ligating bracket, (Groups 4, 5, 6) generated less frictional resistance than did the conventional elastomeric ligature (Group 2). This result is in agreement with the findings of previous studies.(11,21-23,25) However, the innovative ligation systems (Groups 4, 5, 6) were not significantly different from each other or from the SS ligature (Group 1). Theoretically, frictional resistance is depended on 2 factors which are the coefficient of friction and the normal force. In this study, the normal force occurred from the ligation force that perpendicular to a movement direction. In considering of a ligation force, the tube-like shape of the low-friction elastomeric ligature, the low-friction clip ligature, and the passive self-ligating bracket allow the wire to slide through the bracket slot with minimal ligation force, thus creating minimal frictional resistance. In considering of a coefficient of friction, although these ligatures are made from different materials, viz., an elastomer, a composite, and stainless steel, the results show no significant difference in frictional resistance among them. These findings show that the different in the materials used in these ligation methods, differences such as differences in a coefficient of friction, did not affect the frictional resistance in this in vitro study. Thus, the ligation force may be more relevant than a coefficient of friction, and the tube-like designs may reduce frictional resistance.

Loose SS ligation, which is suitable for sliding tooth movement, was used to ligate the SS ligature in this study. The loose SS ligation method may produce low ligation force, as the low-friction elastomeric ligature, the low-friction clip ligature, and the SS passive self-ligating bracket did. Depending on the ligation technique, the SS ligature can generate 0-300g ligation force rendering it difficult to control each ligation to produce the same ligation force.(26,27) In order to minimize such difficulties, all SS ligations were performed by the same individual and using the same pattern.

The other innovative ligation system, the polymeric-coated elastomeric ligature (Group 3) is claimed to reduce friction.(28) However, this study found that the conventional SS brackets ligated with the polymeric-coated elastomeric ligature produced greater frictional resistance than did those with the conventional elastomeric ligature. This findings were supported by some studies such as Griffith *et al*(29), Khambay *et al.*(17) Controversially, some studies such as Arun and Vaz(9), Hain *et al*(28) found that the polymeric-coated elastomeric ligature produced less frictional resistance than the conventional elastomeric ligature.

In considering of a ligation force, Chimenti *et al*(30) found that there was a significantly positive correlation of the regression analysis between the thickness of conventional elastomeric ligatures and frictional force. In addition, the outside diameter of these ligatures also showed a weak positive correlation, but the inside diameter showed no significant correlation with static frictional forces. Therefore, the difference in thickness and outer diameter of elastomeric ligatures affected the frictional resistance. However, the materials in this study, the polymeric-coated elastomeric ligature and the conventional elastomeric ligature, were made by TP Orthodontics of the same material, and having the same size and shape. The difference between the two ligatures is the hydrophilic coating surface of the polymeric-coated elastomeric ligature. Khambay *et al*(27) found that the tensile force of the polymeric-coated elastomeric ligature was not significantly different from that of the conventional elastomeric ligature. This finding suggests that the ligation force generated by both ligature types would be comparable. However, the hydrophilic property of the surface of the polymeric-coated elastomeric ligature used in this study is, therefore, the only factor that was different, and that could affect the frictional resistance. Moreover, Griffith *et al*(29) compared the frictional resistance produced by a polymeric-coated elastomeric ligature, and round and rectangular cross-section conventional elastomeric ligatures. They found that the polymeric-coated elastomeric ligature produces greater frictional resistance than does the round cross-section conventional elastomeric ligature, but less than the rectangular cross-section conventional elastomeric ligature. Furthermore, Khambay *et al*(17) found that the frictional resistance produced by the polymeric-coated elastomeric ligature was greater than that produced by loose SS ligation and by a conventional elastomeric ligature, albeit one produced by a different manufacturer from the one used in this study (3M Unitek, Monrovia, California, USA) in dry conditions. However, the difference in the diameter of the ligatures used in those may have caused the difference in findings. Controversially, two studies(9,28) reported that the polymeric-coated elastomeric ligature produced less frictional resistance than did the regular counterparts in the either dry or wet conditions. Arun and Vaz(9) found that polymeric-coated elastomeric ligatures reduced frictional resistance in comparison to conventional elastomeric ligatures in dry conditions. Hain *et al*(28) found that polymeric-coated elastomeric ligatures, soaked in saliva for 60 minutes prior to testing, produced significantly less frictional resistance than did conventional elastomeric ligatures. Interestingly, the prolonged exposure to saliva affected the frictional resistance. Another finding was that polymeric-coated elastomeric ligatures that had been soaked in saliva for 60 minutes prior to testing produced significantly less friction than did those that had been given just one drop of saliva. Moreover, they also concluded that soaking in saliva led to a reduction in frictional resistance for both the conventional elastomeric ligature and the polymeric-coated elastomeric ligature, but the polymeric-coated elastomeric ligature produced a greater reduction than did the conventional elastomeric ligature. Thus, the difference between dry and wet conditions may have caused the difference in results due to alteration of the surface interaction between the wire, the bracket and the ligature combination.

The recommended size of wire for sliding orthodontic tooth movement when using 0.022×0.028-inch slot brackets is 0.019×0.025 inches(31). However, the 0.021×0.025-inch SS wire was chosen due to using the large size of wire provides an advantage during the experimental model preparation where the two different types of bracket, conventional brackets and self-ligating brackets, having different prescription can be controlled during placement by the wire so that whichever bracket is used can be set in exactly the same passive position.

Although the sliding velocity in this study was 4.348×10^5 times the rate of orthodontic tooth movement; setting the velocity as low as that of clinical tooth movement was not possible due to the limitations of the universal testing machine. Kusy and Whitley(32) found that the coefficients of both static and kinetic friction of SS and nickel titanium (NiTi) wires on SS contact surfaces were independent of sliding velocity (the sliding velocity used in their study was from 10 mm per minute to 5×10^{-3} mm per minute). However, in their study the wires were sliding on SS surfaces instead of on SS brackets. Moreover, normal forces of 500 and 5000 g in their experimental model were far greater than those used clinically.

In addition, Yanase *et al*(33) found that frictional forces between SS brackets and wires increased with the decreases in sliding velocity (the sliding velocities used in their study were from 6 mm per minute to 3×10^{-5} mm per minute). However, in their study the brackets were ligated with elastomeric ligatures. The static frictional resistance depended not only on the sliding friction between wire and ligation force, but also on the elastic deformation of the rubber. On the other hand, Savoldi *et al*(34) found that frictional forces between SS brackets and wires decreased with decreases in sliding velocity (the sliding velocities used in their study were from 0.6 mm per minute to 6×10^{-4} mm per minute). The experimental model in their study used self-ligating brackets, resulting in elimination of static friction from elastic deformation when using elastomeric ligatures. From these findings, the recommended velocity for frictional resistance tests is unclear, and the effect of the velocity on frictional resistance during sliding mechanics is controversial. Moreover, the aim of this study was to compare the frictional resistance among various orthodontic ligation methods. Thus, the velocity in this study was chosen from previous pilot experimental tests in which the velocity of 10 mm per minute best demonstrated the peak of static frictional resistance.

Hain *et al*(28) found that repeating the test five times with the same ligature produced no statistical difference in friction. However, in this study, a new bracket, archwire and ligature were used each time in an effort to be as accurate as possible.

When choosing low friction ligation methods to enhance sliding tooth movement in clinical practice, low-friction elastomeric ligatures, low-friction clip ligatures, and SS passive self-ligating brackets would be more suitable for decreasing frictional resistance than conventional elastomeric ligatures. The maximum static frictional resistance produced by these ligation methods was not significantly different when compared with each other or with the SS ligatures. In addition, the esthetic needs of patients can be fulfilled with low-friction elastomeric ligatures, which is available in many colors. Moreover, low-friction clip ligatures also has semi-transparent features. The most favored feature of both low-friction elastomeric and low-friction clip ligatures is the possibility of turning a conventional bracket system into a low-friction (tube-like) bracket system. Thus, these ligatures can be applied on specific groups of teeth to produce a low level of friction, as desired. However, they also have some inconveniences. For example, in clinical practice, the low-friction elastomeric ligature might be difficult to ligate onto the bracket due to the special shape of the ligature. Although the low-friction clip ligature is not difficult to ligate, as is the low-friction elastomeric ligature, it is more costly than other ligatures. In addition, the low-friction clip ligature is available for only the Metal Bracket from Dentsply Sankin Inc. Thus, it cannot be used with conventional brackets from other manufacturers.

Many studies(12-15,35-37) support the idea that the passive self-ligating bracket produces: low frictional resistance, resulting in reduced patient discomfort; reduction in oral bacterial retention, resulting in improved oral hygiene; and reliable archwire control, due to full archwire engagement. On the other hand, the torque and tip control can be compromised due to the greater play of the archwire in the slot of self-ligating brackets.(38) In addition, the passive self-ligating bracket is high-priced, and requires a special device for archwire removal.(39) Its use leads to a higher incidence of bracket failure than do conventional brackets.(40) Although there were no significant differences in frictional resistance among the SS ligatures and the low-friction ligation methods in this study, a longer clinical chair time was required than with other ligatures, and the SS ligatures generated various ligation forces because of loose or tight ligation methods.(26,27) Thus, these low-friction ligatures should be an alternative choice instead of conventional elastomeric ligatures for frictional resistance reduction during sliding tooth movement.

Although the low-friction elastomeric ligature, the low-friction clip ligature, and the SS passive self-ligating bracket may have some inconveniences, selecting these ligation methods is more beneficial in reducing frictional resistance than using conventional elastomeric ligatures. However, during tooth movement, frictional resistance is influenced not only by the types of ligation methods, but also by various factors, such as amount of debris accumulation(41), masticatory force, corrosion, binding(42), notching, etc. For better understanding of the frictional resistance of the materials in order to provide effective tooth movement without any patient side effects, future clinical studies are highly suggested.

Conclusions

1. Low-friction clip ligatures (Clear Snap, Densply Sankin) provided the lowest mean maximum static frictional resistance.

2. Polymeric-coated elastomeric ligatures (Super Slick Mini Stix, TP Orthodontics) provided the highest mean maximum static frictional resistance.

3. Stainless steel ligatures and tube-like designs (low-friction elastomeric ligatures, low-friction clip ligatures and self-ligating brackets) produce less maximum static frictional resistance than do conventional elastomeric ligatures and polymeric-coated elastomeric ligatures.

Acknowledgements

I would like to express our recognition to Dr. Thanapat Sastraruji, Faculty of Dentistry, Chiang Mai University for his suggestions and valuable guidance about statistical analysis, and Dr. M. Kevin O Carroll, Professor Emeritus of the University of Mississippi School of Dentistry, USA and Faculty Consultant at Chiang Mai University Faculty of Dentistry, Thailand, for language editing for my manuscript.

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