Original Article

Comparison of resistance to sliding in posterior units with various angulations of molar tubes

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Abstract

Background/objectives This study aimed to investigate the effect of one or two brackets on orthodontic frictional forces and to compare frictional forces of posterior segments when a molar tube had different degrees of tipping.

Materials and Methods Five different types of posterior segment templates with six templates per type were constructed. Templates A and B had one and two brackets with an untipped tube, respectively. Templates C, D, and E had two brackets and a 3°, 6° or 9° tipped tube. Each template was coupled with 0.016″ x 0.022″ stainless steel wire and ligated with elastomeric ligatures. Static frictions were determined to compare the resistance to sliding in dry condition.

Results The mean static friction of all templates was statistically different among groups. An additional premolar bracket in the untipped tube templates increased the friction from 103 ± 64 gram to 156 ± 15 gram. The 3°, 6° and 9° tube/wire angulation generated 235 ± 33 gram, 329 ± 49 gram, and 489 ± 63 gram of friction, respectively.

Conclusions This study demonstrated that the number of brackets and tube/wire angulation affected the total resistance. By changing from one to two brackets, the static friction increased 50 gram. Moreover, as little as 1.6-degree tube/wire contact angles above a critical angle generated 80 gram of binding. Thus, the high tube/wire angulation should be avoided when the low frictional force is needed, and vice versa.

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Keywords: binding, friction in posterior units, tipped tube, tube/wire angulation, resistance to sliding

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Introduction

Friction is a basic resistance force that occurs when an object moves or tries to move against another object. This force takes place unless a coefficient of friction equals zero or when there is no normal force (the perpendicular force pushing against each other) (Besançon, 1985). In orthodontics, the position of teeth is adjusted by moving them along an archwire or when an archwire slides through brackets. In both situations, friction is inevitable. For decades, orthodontic practitioners have known that friction is not the only resistance when the teeth are moved. Orthodontic resistance to sliding (RS) was divided into 3 types: classical friction (FR), binding (BI) and notching (NO) (Kusy and Whitley, 1997). Classical friction depends on the method of ligation. When there is a clearance between an archwire and a bracket, classical friction is dominant (Kusy and Whitley, 1999). But when a contact angle between a bracket and an archwire exceeds a critical angle, binding plays an important role (Tselepis et al., 1994; Whitley and Kusy, 2007). Notching occurs when an archwire is deformed. The tooth stops moving when a bracket stumbles on a notched archwire. The tooth continues to move if the notch is released (Burrow, 2009). Since resistance to sliding appears to occur almost all the time, understanding the principle of it can enhance the efficiency of utilizing orthodontic equipment.

Previous studies have defined various determinants that influence resistance to sliding, for example, archwire materials (Drescher et al., 1989) and bracket materials (Bazakidou et al., 1997; Pratten et al., 1990), the method of ligation (Bednar et al., 1991; Hain et al., 2006), bracket design (Ehsani et al., 2009; Liu et al., 2013), bracket/wire angulation (Articolo and Kusy, 1999; Frank and Nikolai, 1980) and biological factors (Nanda, 1997; Prattenet al., 1990). From results of laboratory and clinical studies, bracket/wire angulation has been found to be more significant than previously thought (Burrow, 2009). Friction of a single bracket with different kinds of archwires with 0°, 3° , 6° and 10° of bracket/wire angulations was compared (Frank and Nikolai, 1980). The results implied that the more bracket/wire angulation, the more resistance to sliding. The regression analysis revealed that after increasing the bracket/wire contact angle, the ligation influence (classical friction) was preceded by dimension, shape and material of archwire which were consequences of binding. Since definition and factors of binding and classical friction are different (Thorstenson and Kusy, 2003), it is important to study these factors.

Most studies in which binding was investigated made use of a single tipped bracket which is a good representation of a canine retraction unit. Under these conditions both mesial and distal wings of a bracket press on an archwire, thus creating binding. In a posterior unit, when a last tube is tipped, it only presses a wire at a mesial side, not on both sides of the tube. Therefore, binding from a tipped tube may be less than inding from a tipped canine bracket. Moreover, a posterior unit usually consists of one or two brackets and a tube, while in the canine retraction unit has only one bracket. Thus, the classical friction in a posterior unit may has larger effect on the total resistance to sliding than in a canine retraction unit. To date, most of studies reported that binding is a major component when there is a bracket/wire angulation, but all studies simulated a wire sliding through a canine bracket. Since the structure of the posterior unit is different, an understanding of a total resistance to sliding in a posterior unit should not be neglected. This study aimed (i) to compare the resistance to sliding in a posterior unit when the number of brackets is increased from one to two brackets and (ii) to compare the resistance to sliding when the tube/wire angulation increases.

Materials and methods

The following brackets, tubes and wires were used:

1. Upper bicuspid universal standard stainless steel brackets with a slot size of 0.018″ x 0.025″ (ORMCO, Glendora, CA)

2. Upper left first molar standard stainless steel tubes with a slot size of 0.018″ x 0.025″ (ORMCO, Glendora, CA)

3. 0.016″ x 0.022″ straight stainless steel wires (ORMCO, Glendora, CA)

The critical angle calculation

The critical angle (θc) was calculated as an equation stated (Kusy and Whitley, 1999).

$$\theta c = 57.32^{\circ}[1-[SIZE/SLOT]]/[WIDTH/SLOT]$$

SLOT (bracket dimension at a floor of the slot) of molar tubes was measured under a stereomicroscope for actual SLOT size. Each tube side was measured 2 times and was calculated to find a mean of SLOT. The WIDTH (mesiodistal width of the tube) and the SIZE (dimension of the archwire engaging onto the floor of the slot) of wires were measured with a Digital Caliper Micrometer (Mitutoyo, Japan).

Jig preparation

Thirty pieces of posterior unit acrylic templates were divided into 5 types, templates A-E [Figure 1]. For all templates, the interbracket distance was 8 mm while the distance between the bracket and the tube was 9 mm to simulate a posterior unit. The 0.018″ x 0.025″ stainless steel wire was used to align brackets and tubes. All brackets and tubes were mounted and led by guiding lines on the template. The guiding lines were constructed using a computer program and printed on templates. Guiding brackets were made at a distance of 1.5 mm from the template, under a stereomicroscope (SZ 61TR, OLYMPUS, Japan). The guiding brackets were built to ensure that all brackets

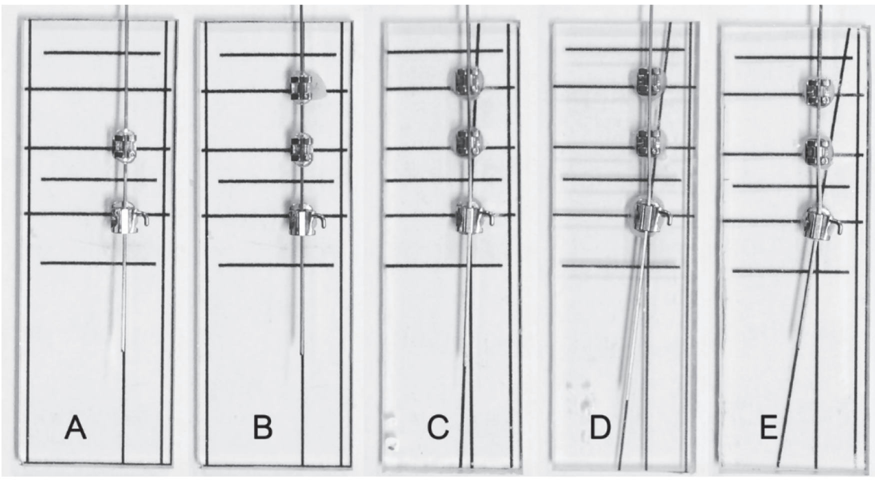

Figure 1: Five types of posterior segment templates (A) Template A consisted of one bracket and a 0 degree tube, (B) Template B consisted of two brackets and a 0 degree tube, (C) Template C had two brackets and a molar tube with 3 degrees tube/wire angulation, (D) Template D had two brackets and a molar tube with 6 degrees tube/wire angulation, (E) Template E had two brackets and a molar tube with 9 degrees tube/wire angulation.

and tubes were in the same plane [Figure 2A]. In templates A and B, brackets and tube were arranged by the 0.018″ x 0.025″ stainless steel wire with the guiding brackets. In templates C, D and E, a tube was placed along the guiding line with an angle of 3°, 6°, and 9° respectively [Figure 2B]. After aligning the tubes, brackets were placed on the template using the guiding brackets. Transbond^{XT} (3M Unitek, CA) was used to mount all brackets and tubes.

Testing wire preparation

The 0.016″ x 0.022″ straight stainless steel wires were cut into 60 mm per piece and were bent by a Tweed loop forming plier to form a hook. The highest point of the hook was in the same line to the straight part of the wire [Figure 2C].

Frictional testing

Before testing, the brackets and wires were wiped with ethanol to remove any debris. The testing wire was inserted into the template and secured by transparent elastomeric ligatures (ORMCO, Glendora CA). The ligation was performed by one operator. For simulation of an archwire movement, the posterior unit template was attached to a lower fixed part of the Universal testing machine (SHIMADZU, AG-10TA Autograph, Japan) and the testing wire was hanged to the moving part of the Universal testing machine [Figure 2D]. The test started immediately after the testing wire was ligated and the template was fixed to the Universal testing machine. Each type of template was made in six-fold and tested with a new wire each time. Thirty combinations were measured under a dry situation at room temperature (27 ± 1°C). Each wire was pulled at a crosshead speed of 10 mm/min for 2 mm. Static friction was used to calculate the mean resistance to sliding.

Data were analyzed using SPSSv.22® (IBM, Armonk, NY). The Shapiro-Wilk test was used to evaluate whether the distribution was normal. Then, independent t-test, one-way analysis of variance (ANOVA) and Tukey HDS test was performed at a probability level of 0.05.

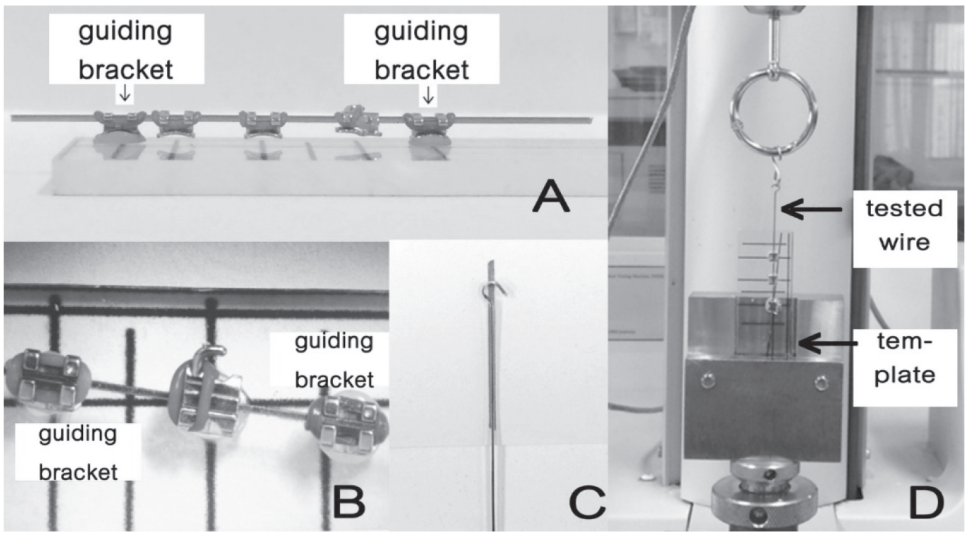

Figure 2A-D: (A) Guiding brackets helped aligning brackets and a tube, (B) Tube placement under stereomicroscope by guided brackets, (C) A testing wire was bended by a Tweed loop forming plier and the highest point of the hook was in the same line to the straight part of the wire, (D) The arrangement of a posterior template and a testing wire.

A jig of group B template was specially made to test the reliability of the operator ligating the brackets. The stainless steel wire was secured with transparent elastomeric ligature by the operator and tested 10 times to get values of friction. The data were used to calculate the Dahlberg formula (Houston, 1983). The result from the formula was 18 gram for one operator tying elastomeric ligature. The standard error which was lower than half of the mean differences of the compared groups was accepted (Baumrind and Frantz, 1971)

Results

Critical angle

Dimensional measurement of wires and brackets showed that the actual SIZE of 0.016″ x 0.022″ "wires was 0.0155". The average WIDTH of the brackets was 0.1315 ± 0.0005 inches and the average SLOT of brackets was 0.0188 ± 0.0002 inches. These variables were used to calculate θc, which was found to be 1.4 degrees.

Effect of number of brackets on static friction

The average static friction of template A was 103 ± 64 gram. When the number of brackets increased from one to two, the static friction increased to 156 ± 15 gram, thus a 50 percent increased. The mean frictional force from template A and B showed a significant difference with $P < 0.001$ (Table 1).

Table 1: Comparison of mean static frictional forces(g) between one and two brackets in the posterior segments.

	Mean ± SD	**P-value***
Template A	103 ± 64	< 0.001
Template B	156 ± 15	

*t-test was employed to find P-value.

Effect of tube/archwire angulation on static friction

The frictional force from template *C* was 235 ± 33 gram. A double frictional force was found in template D when compared to template B, being 329 ± 49 gram. With a 9° tipped tube, the frictional force was 489 ± 63 gram. The one-way ANOVA test was used to compare mean static frictional force between templates B, C, D and E. The P-value was less than 0.001. A Tukey HSD was performed to determine significant differences among groups. The results in Table 2 showed that each group was significantly different from one another.

Discussion

The actual critical angle calculation compared to the theoretical critical angle calculation

The critical contact angle (θc) is the first touched angle when a bracket is tipped and touches an archwire. The actual θc was not equal to the theoretical θc as a result of the uneven slot of brackets and size of archwires to its nominal size (Kusy and Whitley, 1999). From the equation of that study, 0.016″ x 0.022″ stainless steel wire and a 0.018″ slot tube theoretically created a 0.9 degree critical angle while an actual critical angle of this tube and wire combination was 1.4 degrees. This demonstrated that nearly 50 percent of the tipped

Table 2: Comparison of mean static frictional forces(g) with different tube/bracket angulations.

	Mean ± SD	**Overall P-value***	**Significant group****
Template B	156 ± 15	<0.001	B vs C (P = 0.026)
Template C	235 ± 33		B vs D (P < 0.001)
Template D	329 ± 49		B vs E (P < 0.001)
Template E	489 ± 63		C vs D (P = 0.006)
			C vs E (P < 0.001)
			D vs E (P < 0.001)

*one-way ANOVA was used to define P-value.

**Tukey HSD was used to determine the significant groups at 0.05 level.

B = Template B; C = Template C; D = Template D; E = Template E angle was a value allowed to occur beyond an expected value before the binding phenomenon involved. Since the critical angle was 1.4 degrees, the templates A and B were in passive configuration and the templates C, D and E were all in the active configuration.

Effect of either one or two brackets on static friction in passive configuration

As the tubes of template A and B were in passive configuration, classical friction was the only component in resistance to sliding of these two templates. When two instead of one bracket present, classical friction was expected to elevate twice because the normal force increased one time. The ratio of friction of one bracket/two brackets to be 1.5 which was not as high as the expected value. This appears to be in line with previous studies. Previous study showed the ratio of static friction between one bracket/two brackets was 1.27 and 1.2 in 0.022″ slot-size brackets with the size of the stainless steel wire as follows 0.017″ x 0.025″ and 0.018″ x 0.025″, respectively (Ireland et al., 1991). Another study reported that when the number of brackets was doubled, the rise of friction depended on the size of the wires (Taylor and Ison, 1996). The ratios of static friction between one bracket/two brackets were 2.37, 2.17 and 1.37 in 0.022″ brackets with the size of the stainless steel wire as follows 0.016″ x 0.022″, 0.017″ x 0.025″ and 0.018″ x 0.025″. The thicker the wire, the smaller the ratio was. The value of friction from these two studies cannot be compared directly with this study because of differences in the tested bracket slot and wire size. Nevertheless, our results are quite comparable to these two studies.

Effect of tube/wire angulation on static friction

The tube/archwire contact angles in templates C, D and E were 2, 4 and 8 fold higher than their critical angles (their $\theta c = 1.4°$). Friction increased by nearly 50 percent when tube/wire angulation was 3° instead of 0° (from 156 ± 15 gram in template B to 235 ± 33 gram in template C). These data show that only an increase of 1.6° over θc, resulted in an increased friction of about 80 gram. Thus, an increase in angulation of only 1.6 degrees had a stronger effect than the addition of an extra bracket (80 gram compared to 50 gram). When the tube/wire increased to 6 degrees, being 4 times the θc, the RS was two times its passive configuration, 156 to 329 gram. When the tube/wire angulation was 9 degrees (8 times the θc), the total friction increased by another 200 percent, from 156 to 489 gram. These results demonstrated a proportional increasing in resistance to sliding when the tube/wire angulation increased.

The results of this study showed that both increasing the number of bracket as well as the bracket/wire angulation has impact on resistance to sliding. By comparison with increasing the number of brackets, the angulation of the tube has stronger influenced on the resistance to sliding. But when compared to canine retraction units from other studies, the tipped tube in a posterior unit did not have as much impact on the resistance to sliding as in the canine retraction unit. From previous studies, Percent BI (BI/total RS x 100) ranged from 73 to 99% in a canine retraction unit (Articolo and Kusy, 1999; Frank and Nikolai, 1980). In comparison to this study, 3, 6, 9-degree tube wire angulation created 33.62%, 52.58% and 68.10%BI, respectively. The lower percent BI showed the more classical friction effect in the total resistance to sliding. This demonstrated that controlling both classical friction and binding is important in a posterior unit. Unlike in the canine retraction unit that binding seem to be an essential component when a canine is tipped. By plotting a graph from previous studies compared to this study (Articolo and Kusy, 1999; Frank and Nikolai, 1980), the binding from studies of canine retraction unit showed a similar trend of binding values despite a different in archwire size [Figure 3].

Most of the frictional studies in orthodontics use static friction as a representative of resistance to sliding because tooth movement is very slow (a quad static movement). Also, static friction and dynamic friction were found indifferent (Taylor and Ison, 1996). Since static friction was easy to obtain and proved to be reproducible, it was chosen to be used in this study. The method of ligation affected only classical friction and did not affect binding (Thorstenson and Kusy, 2003), so this study was designed not to vary the number of brackets when the tube was tipped. This study was design to use 2 premolar brackets instead of a combination of a canine bracket and a premolar bracket because a canine bracket is wider than a premolar bracket. The dimension of the bracket might result in a different level of the elastomeric stretch which could make the increasing friction ratio between two/one bracket inaccurate (Ireland et al., 1991). In addition, the static friction from this study could not represented a clinical friction value because it was conducted in vitro.

Clinical implication

The requirement of friction in a posterior unit depends on a clinical situation. For example, when a canine is retracted in a maximum anchorage situation, a posterior unit needs to have maximum resistance to sliding. Therefore, various methods to modify the classical friction (Nanda, 1997) such as changing the ligation method (Bazakidou et al., 1997; Edwards et al., 1995; Hain et al., 2006). In addition, the results of this

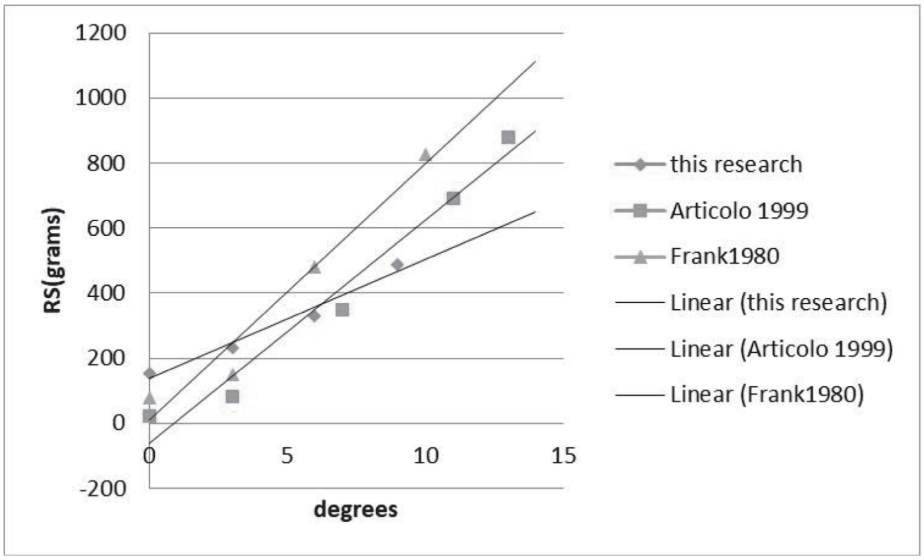

Figure 3: Trendlines of the total resistance to sliding when bracket/wire configuration were altered.

study not only illustrated that the adding number of brackets increased classical friction, but rising tube/wire angulation also enhanced protection of anchorage loss. By adding an extra bracket to a posterior unit, classical friction became higher. However, it increased merely 50 percent, not double. Moreover, only a small value above θc made the resistance to sliding rise sharply. The tipping molar tube could create a large amount of friction (approximately 80 gram when the tube/wire angulation was 1.6 degrees above the critical angle). Clinicians can adapt this findings to the clinical practice by bending the wire end to create tube/wire angulation as anchorage bending in front of a molar tube (Mulligan, 1982) or using a special designed molar tube of the PASS technique (Chen et al., 2015). Also, when the lowest friction is needed in a posterior unit, for instance, in anterior retraction phase, well aligned tube and brackets are recommended. On the other hand, to enhance protection of anchorage loss, binding can play an important role.

Conclusion

1. Friction increased by 50 percent when an extra bracket was added.

2. A small tube/wire angulation, which was 1.6° beyond the critical angel, generated higher binding than classical friction from adding an extra bracket.

3. At a 3-degree interval of tube/wire angulation, binding did not rise proportionally. At the first 3-degree interval (3° to 6°), binding increased by 100 gram, while the binding rose by another 160 gram at a second 3-degree interval (6° to 9°).

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