Original Article

The Influence of Canine Angulation on the Frictional Resistance in Posterior Units

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Abstract

The aim of this study was to compare the frictional resistance in posterior units, which are influenced by canine angulation, with different wire sizes. Stainless steel (SS) arch wires, 0.016” x 0.016” and 0.016” x 0.022”, were ligated to posterior units consisting of different numbers of posterior 0.018-inch slot bracket and tube. The test assembly was fixed to a universal testing machine with 50-N load cell. To simulate the situation that a canine was distalized and tipped when using sliding mechanics, the wires were angled (0°, 5°, 10°, 15°) at the distance 12.5 mm from the mesial wing of premolar bracket and drawn through the units at a cross-head speed of 10 mm/min over 2 mm at room temperature. The maximum frictional resistance was measured. Frictional resistance in a posterior unit increased with the increasing angulation and wire size. Among the different angulations, wire sizes, and posterior unit combinations, a 15° angle 0.016” x 0.022” SS wire in a one-bracket + one-tube unit had the greatest frictional resistance. Frictional resistance in the 15° and 10° angle groups were significantly greater when compared to the 0° and 5° angle groups for nearly all bracket-wire combinations. The 0.016” x 0.022” SS wires demonstrated significantly greater frictional resistance than 0.016” x 0.016” SS wires in a one bracket + one tube unit with all wire angles. Frictional resistance of the posterior unit increased when the wire angle and the wire size increased. These results implied that increased canine angulation during the canine retraction phase increases frictional resistance of the posterior unit clinically.

Keywords: Canine angulation, Friction, Orthodontic archwire

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Introduction

Orthodontic tooth movement during space closure can be achieved through sliding mechanics, which involves either the brackets sliding along an archwire or the archwire moving through brackets and tubes. The sectional retraction technique for upper and lower canines is similar to segmented arch mechanics, in which the canine is retracted to the first premolar extraction site by elastic and moved along a guided sectional archwire. The resistance to sliding, called the "frictional resistance" can occur during tooth movement. Kusy and Whitley[1] categorized frictional resistance into three components: (1) classical friction; (2) binding; and (3) notching. The frictional resistance is known to be a major problem in sliding mechanics during space closure in orthodontic treatment in both sectional and continuous archwire.[1-4] The clinical side effects that could occur during the canine retraction phase are distal canine tipping and rotate into a premolar extraction site (Fig. 1).[5,6]

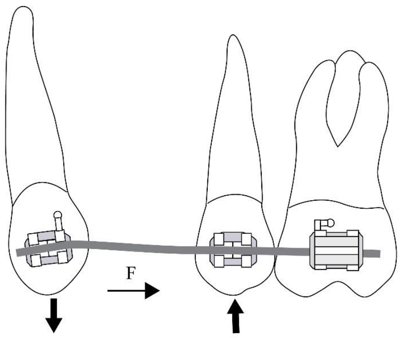

Figure 1 *Distal canine tipping is a side effect of canine retraction with sliding mechanics*

Shpack *et al.*[7] reported that during canine retraction, the amount of distal canine tipping was 6.1° in a tipping mechanics group and - 0.8° in a bodily mechanics group. As Ziegler *et al.*[8] have found, distal tipping of the canine occurred with 0.2° - 4.9° per millimeter of movement during canine retraction using sliding mechanics. The frictional resistance has been shown to increase proportionally, as the amount of canine tipping increased.[5]

Unpredictable and excessive frictional resistance is undesirable in orthodontic treatment, as it leads to unwanted tooth movement and considerably less efficient due to friction and binding. Orthodontists, therefore, would generally apply an additional force to compensate for such reduction in efficiency. However, lighter force is more preferable in orthodontic tooth movement since it is more comfortable for the patients and less compromising to the anchorage unit.[9]

It is important to understand and be able to control frictional resistance in posterior units during the use of orthodontic appliances. It can help improve the efficiency of an appliance system, determine in part the effectiveness of tooth movement and anchorage control, and eliminate undesirable side effects. Most studies investigated frictional resistance by using a single tipped canine bracket with different angles as a representation of a tipping canine. No studies have investigated frictional resistance in posterior teeth units when a canine bracket is tipped at different angles and the information of this situation is unknown. Thus, the aim of this study was to determine the frictional resistance in posterior units during canine retraction under different degrees of distally tipped canine, different wire dimensions, and different numbers of posterior bracket and tube.

Materials and methods

The sample size was determined based on the findings of a previous study[10] by using G*Power 3.1.9.2 (Universität Düsseldorf, Germany) with the alpha significance level of 0.05 and a beta of 0.20. The sample size calculated for each group was six templates.

This study used the upper left standard edgewise stainless-steel premolar bracket and upper first molar tube with a slot 0.018" x 0.025" (ORMCO, Glendora, CA), which represented a posterior unit. A custom-made model (Fig. 2) was used to test 0.016" x 0.022" and 0.016" x 0.016" straight stainless steel (SS) wires (ORMCO).

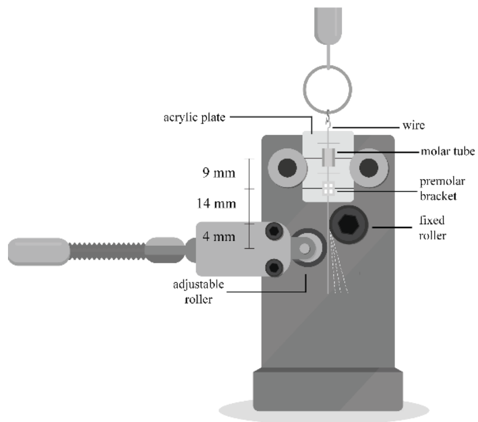

Figure 2 *The custom-made model with inner acrylic template*

The custom-made model consisted of two rollers; the first, a fixed roller, acted as the distal wing of a canine bracket; the second, an adjustable roller, represented the mesial wing of a canine bracket. In order to simulate interbracket distance of the posterior buccal segment, the distance between the first roller and the premolar bracket was 14 mm, and the molar tube was 9 mm away from the premolar bracket (center to center). The 0.018” x 0.025” SS wire with a guiding bracket and tube was used to align the premolar bracket and the molar tube on the inner acrylic template (Fig. 3) in order to control the buccolingual and occluso gingival dimension of all brackets and tubes.

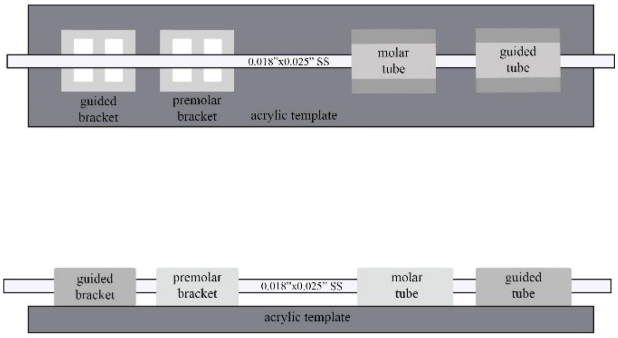

Figure 3 *To control the buccolingual and occluso gingival alignment of all brackets and tubes, the premolar bracket and molar tube were aligned with a guiding bracket, tube, and 0.018” x 0.025” SS straight wire on the acrylic template*

Light-cured adhesive (Transbond®XT, 3M Unitek, Monrovia, CA) was used to fix the bracket and tube on an acrylic template. Ninety-six acrylic templates were divided into 16 groups by degrees of wire bend (0°, 5°, 10°, 15°), wire sizes (0.016” x 0.022”; 0.016” x 0.016”), and the number of brackets and tubes (one premolar bracket + one molar tube unit, or only one premolar bracket unit). The wires were cut into 60-mm lengths and tied to the bracket by elastomeric ligatures. The acrylic template was attached to the custom-made model, the model placed in the testing holder and fixed to the universal testing machine (Shimadzu, AG-10TA Autograph, Kyoto, Japan) with 50 N load cell. The wire was positioned at the center of the bracket-tube slots and the rollers, drawn through the units at a cross-head speed of 10 mm/min for 2 mm at room temperature and no swing during the pull. To measure frictional resistance, the wire-bracket combinations were tested at four different angles (0°, 5°, 10°, 15°), and each measurement was carried out six times (Fig. 4A). Static friction was measured to calculate the mean frictional resistance in gram-force. Each wire, bracket and tube were used only once to avoid abrasion after testing and to rule out possible wear effects or errors from repeated use.

The frictional resistance of the roller was measured by pulling a straight wire through the device without the posterior unit (Fig. 4B), and the measured frictional resistance was deducted from the results with the posterior unit in order to obtain the frictional resistance of the posterior unit alone. To determine the roller resistance, the wire was gripped at the 12.5 mm length from the center of the first roller, where the mesial wing of the premolar bracket would be, with the testing holder of a universal testing machine and aligned in the same direction as the bracket slot. This was repeated using both wire sizes at all four angles.

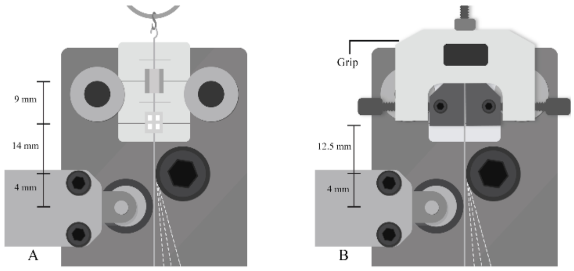

Figure 4 *A, a wire was tested with different angles in the testing machine. B, frictional resistance of the roller was measured at different angles*

Statistical analysis

The means and standard deviations of the frictional resistance in each experimental group were calculated and analyzed with SPSS statistical software version 22 (IBM Inc., Chicago, IL,). Normal distribution of the data was confirmed using the Kolmogorov-Smirnov test. The differences in wire sizes and the number of brackets and tubes were compared by using the independent *t*-test. One-way analysis of variance and Tukey’s post hoc honestly significant difference (HSD) test were used to compare within wire angle groups. The level of statistical significance was set at $p < 0.05$.

Results

The effect of angulation

Results indicated that the means and standard deviations of frictional resistance increased as angulation increased in all bracket-wire combinations (Table 1 and Fig. 5).

Table 1 *Comparison of statistical analysis of static frictional resistance (gram) for each wire-bracket combination and wire angle*

	wire size	0°		5°		10°		15°		p-value
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
1 bracket	0.016" x 0.016"	142.7[a]	3.8	150.2[a]	2.2	156.9[a]	3.8	184.3[b]	4.3	.000*
	0.016" x 0.022"	141.4[c]	4.0	152.6[c]	6.5	184.0[d]	9.0	185.3[d]	10.9	.000*
1 bracket +1 tube	0.016" x 0.016"	138.4[e]	2.0	147.2[e]	4.5	186.3[f]	3.9	213.8[i]	3.0	.000*
	0.016" x 0.022"	169.1[j]	6.1	172.5[j]	8.6	200.2[k]	10.6	224.2[l]	6.9	.000*
Roller	0.016" x 0.016"	0.68	0.57	3.18	0.57	3.64	0.72	6.39	1.91	
	0.016" x 0.022"	0.86	0.65	3.01	0.53	4.83	0.97	8.74	2.28	

*For each row, values with the same superscript letter are not significantly different, One-way ANOVA test, *Significantly ($p < 0.05$)*
[a,b] for 0.016"x0.016" SS wire in a one-bracket unit, [c,d] for 0.016"x0.022" SS wire in a one-bracket unit
[e,f,i] for 0.016"x0.016" SS wire in a one-bracket + one-tube unit, [j,k,l] for 0.016"x0.022" SS wire in a one-bracket + one-tube unit

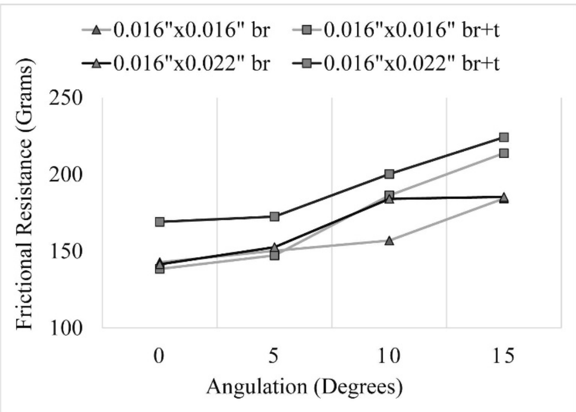

Figure 5 *The means value of frictional resistance; 0.016" x 0.016" SS with a one-bracket unit, 0.016" x 0.016" SS with a one-bracket + tube unit, 0.016" x 0.022" SS with a one-bracket unit, and 0.016" x 0.022" SS with a one-bracket + one-tube unit*

The average frictional resistance of 0.016" x 0.022" SS wires with one-bracket + one-tube unit at the 0°, 5°, 10°, 15° angles were 169.1±6.1, 172.5±8.6, 200.2±10.6, 224.2±6.8 grams, respectively. Tukey's HSD test (Table 1) indicated frictional resistances in the 10° angle groups were significantly higher frictional resistance when compared with the 0° and 5° angle groups for all bracket-wire combinations, except for 0.016" x 0.016" SS wires with the single bracket unit. At a 10° angle, the frictional resistance of 0.016" x 0.016" SS wires with the one-bracket + one-tube unit, 0.016" x 0.022" SS wires with the one-bracket + one-tube unit, 0.016" x 0.016" SS wires with the single bracket unit, 0.016" x 0.022" SS wires with the single bracket unit were 186.3±3.9, 200.2±10.6, 156.9±3.8, 184.0±9.0 grams, respectively. Nevertheless, no significant difference was found between frictional resistance in the 5° angle groups compared to the 0° angle groups in all bracket-wire combinations. Lastly, statistically significant differences were found when comparing frictional resistance of the 15° angle groups to the 0°, 5°, and 10° angle groups, except for 0.016" x 0.022" SS wires with the single bracket unit at a 10° angle.

The effect of wire size

The frictional resistance of 0.016" x 0.022" SS wires was significantly greater than 0.016" x 0.016" SS wires in every bracket-tube combination and angle, except for a single bracket unit at 0°, 5°, and 15° angles (Table 2).

Table 2 *Comparison of statistical analysis of static frictional resistance (grams) for each wire size*

	1 bracket			1 bracket + 1 tube		
Angulation	0.016" x 0.016" SS	0.016" x 0.022" SS	*p*-value	0.016" x 0.016" SS	0.016" x 0.022" SS	*p*-value
0°	142.7	141.4	.754	138.4	169.1	.000*
5°	150.2	152.6	.498	147.2	172.5	.001*
10°	156.9	184.0	.000*	186.3	200.2	.038*
15°	184.3	185.3	.875	213.8	224.2	.029*

*Frictional force data are presented as mean. Independent t-test, *Significantly ($p < 0.05$)*

The effect of the number of brackets-tubes

The frictional resistance of one-bracket + one-tube units were significantly greater than in the single bracket units for all wire sizes and angles, except for the 0.016” x 0.016” SS wires at 0° and 5° angles (Table 3).

Table 3 *Comparison of statistical analysis of static frictional resistance (grams) for each number of a bracket-tube*

	0.016” x 0.016” SS			0.016” x 0.022” SS		
Angulation	1 bracket	1 bracket + 1 tube	*p*-value	1 bracket	1 bracket + 1 tube	*p*-value
0°	142.7	138.4	.350	141.4	169.1	.000*
5°	150.2	147.2	.572	152.6	172.5	.001*
10°	156.9	186.3	.000*	184.0	200.2	.017*
15°	184.3	213.8	.000*	185.3	224.2	.000*

*Frictional force data are presented as mean. Independent t-test, *Significantly ($p < 0.05$)*

Discussion

The posterior unit of the canine retraction phase consists of a premolar bracket and a molar tube. This experiment simulated the main archwire bending caused by the tipping of the canine bracket. The rollers represented the canine bracket and created the preferred wire angles. When the wire was bent, frictional resistance could be found at the roller. In our study, frictional resistance of the roller was less than 10 grams at each wire angle. Since the frictionless rollers could not be constructed, the frictional resistance of the posterior unit could not be directly measured. Therefore, the frictional resistance obtained from the test was subtracted from the mean frictional resistance of the roller. To reduce the complexity of the force system, instead of pushing the wire into the canine bracket at the same angle every time, it was opted for the rollers to represent a tipped canine bracket.

Most of the frictional resistances of the one-bracket + one-tube units were significantly greater than in the single bracket units. Total frictional resistance was higher when a first molar tube was added. According to the results, frictional resistance in the one-bracket units had more than 80 % of the frictional resistance in the one-bracket + one-tube units. This implied that the nearest bracket to the extraction space has more influence on the frictional resistance than the more distal bracket. This finding was in accordance with previous studies. Ireland *et al.*[11] showed one-bracket units have frictional resistance 62 % - 86 % of two-brackets + one-tube units with NiTi and SS wire. However, the value of frictional resistance from the study could not be validly compared with our study because of the difference in bracket slot, wire size, angulation, and testing apparatus.

Several studies found that larger wire sizes were associated with increased frictional resistance.[12-15] These findings in this study, that the frictional resistance increased with increasing wire size, from 0.016" x 0.016" to 0.016" x 0.022", were similar to other studies.[12-16] Stiffness of the wires depends on the cross-sectional dimension in the bending direction of rectangular wires[17], and the smaller wire size with less stiffness was associated with a lower bracket/wire contact force for a given angulation and resulted in a lower static frictional resistance.[18] Nevertheless, the results showed that the larger wire has insignificantly less frictional resistance than the smaller wire, one bracket unit, at a 0° angle. Michelberger *et al.*[19] reported that the coefficient of friction of SS archwires was generally unaffected by the archwire dimension. The mean values of the coefficient of static friction for the 0.016" SS wire were equal to the 0.022" SS archwire surfaces tested with SS bracket.[19]

The present study showed that the frictional resistance did not increase proportionately with the angle. The resistance increased by 4 % - 27 % when the angle increased from 5° to 10°. Many studies[12,20] evaluated resistance to sliding with various angles and found that greater resistance to sliding occurred with increasing angles and when there was no clearance between wire and bracket. In this condition, angulation was above the critical angle, and the binding component was added to resistance to sliding.[1]

The results from this study showed that the frictional resistance of the posterior unit increased when the wire angulation increased. Profitt *et al.*[21] suggested that the net desired force for sliding teeth on an archwire was 100 grams per tooth. In this study, the average frictional resistance of 0.016" x 0.022" SS wires with a one-bracket + one-tube unit at 5° and 10° angles were 172.5 and 200.2 grams, respectively. Therefore, to prevent anchorage loss, in the case of 5 to 10 degrees of canine tipping, the optimal force for canine retraction should not exceed 300 grams. Previous studies have shown, the degrees of the distal canine tipping occur 0.2° - 4.9° per millimeter with sliding mechanics[8] and the force of the elastomeric chain degrades over time, the wire became straighter, resulting in a more canine upright.[6] From the statistical analysis, frictional resistances of most bracket-wire combinations at a 10° angle were significantly greater than 0° and 5° angles. Therefore, in a clinical situation, if canine angulation is not more than 10 degrees, an orthodontist can continue to retract canines without re-leveling. In other words, complete leveling of the arch before using sliding mechanics is considered to be unnecessary. On the other hand, to minimize frictional resistance, re-leveling would be required if the canine angulation is more than 10 degrees.

Conclusions

1. The angle of the wire, as required by canine angulation, the size of the wire, and the configuration of the posterior unit (bracket and tube) influences frictional resistance.
2. As the wire angle increased, the frictional resistance of the posterior unit increased. Canine uprighting is required to reduce frictional resistance if canine angulation is more than 10 degrees.
3. The 0° and 5° angulated archwires were not significantly different in frictional resistance in the posterior unit.
4. The larger wire resulted in increased frictional resistance at all angles.

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