Comparative Evaluation of Frictional Forces of Conventional and Self-ligating Bracket Systems: An in vitro Study

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ABSTRACT

Introduction: Among the numerous factors affecting friction between the bracket-archwire interface, the method of ligation is one of the most important. A number of ways have been proposed to reduce this friction, including self-ligating brackets and more recently Slide™ (Leone SpA, Firenze, Italy) low-friction ligatures.

Aim: This study aims to compare the frictional forces generated by three different ligation methods; conventional ligation, self-ligation and slide low-friction ligation, using metallic and ceramic brackets.

Materials and methods: Three models with ten aligned brackets (standard, self-ligating and ceramic) were used with conventional and low-friction ligatures to study the frictional resistance generated with 0.016” nitinol and 0.019” × 0.025” stainless steel wires.

Results: Conventional ligation produced the greatest friction regardless of wire or bracket combination used. With smaller round wires, the self-ligating system exhibited less friction than low-friction ligation and with higher dimension archwires it exhibited greater friction. Slide low-friction ligatures were able to reduce the friction of ceramic brackets in a similar way to stainless steel brackets.

Conclusion: Slide low-friction ligatures produced a reduction in friction with both metallic and ceramic brackets to a level comparable to that of self-ligating brackets.

Keywords: Friction, Low-friction ligation, Self-ligating brackets.

INTRODUCTION

The success of orthodontic tooth movement with preadjusted appliances depends to a large extent on the ability of the orthodontic archwire to slide through brackets and tubes. The major disadvantage with the use of sliding mechanics is the friction that is generated between the bracket and the archwire during orthodontic tooth movement. Friction is defined as ‘the force tangential to the common boundary of two bodies in contact that resists the motion of one relative to the other. The magnitude of the frictional force is proportional to the normal force that pushes the two surfaces together’. Static friction is considered to have a greater importance in orthodontics because it needs to be overcome each time the tooth moves a little.1 A number of studies have identified the principal factors that may influence orthodontic frictional resistance:2 Relative bracket-archwire clearances, archwire size, archwire cross-section (round vs rectangular wires), torque at the bracket-wire interface, surface conditions of the archwires and bracket slot, bracket and archwire materials, bracket slot width, bracket type (conventional vs self-ligating brackets), type and force of archwire ligation. Schumacher et al found that friction was determined mostly by the type and force of ligation.3

To overcome the disadvantages of conventional ligation techniques, self-ligating brackets were introduced. Its advantages are reduction in chairside time and minimal friction for better sliding mechanics. Self-ligating brackets with passive slides exhibits lower frictional resistance than self-ligating brackets with active clips because of the differences in ligation force and slot geometry.4

Ceramic brackets were developed in the 1980s to improve esthetics during orthodontic treatment. In clinical use, however, they have problems including brittleness leading to bracket or tie-wing failure, iatrogenic enamel damage during debonding, enamel wear of opposing teeth in contact, and high frictional resistance to sliding mechanics.5,6

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Recently, new low-friction ligatures (Slide™, Leone, Firenze, Italy) have been introduced; similar to elastic ligatures, but with an anterior part that is more rigid and similar to the mechanical device of self-ligating brackets. It can be applied in the same way as classical elastic ligatures and, once on the bracket, it self-ligates on the slot forming a ‘tube-like’ structure, allowing the archwire to slide freely and to produce its effects more readily on the dentoalveolar components. The aims of the present study were to compare the frictional forces generated by Slide low-friction ligatures with that of self-ligation and conventional ligation methods and to find out whether Slide™ low-friction ligatures were able to provide any reduction in friction with ceramic and stainless steel brackets.

MATERIALS AND METHODS

Three types of brackets and two types of archwires were used in combination with three different ligation methods to evaluate the amount of resistance to sliding present. Friction was measured as the load necessary to pull the archwire through the brackets when the archwire was secured to the brackets with different ligation methods.

The testing model used in this study was as described by Tecco et al. The testing model comprised a metal bar of approximately 10 × 3.5 × 1.0 cm dimensions. On one of the larger surfaces of the metal bar, ten brackets (to represent the upper right second premolar to the upper left second premolar) were bonded using cyanoacrylate adhesive (Fevi Kwik, Pidilite Industries, Mumbai). For alignment of the brackets, a straight length of 0.021” × 0.028” stainless steel archwire was inserted in the slots of the brackets, without ligation, before bonding. The brackets were kept at a distance of 8.5 mm apart. All brackets were oriented in the direction that it would have been in the oral cavity. After bonding of the brackets on the metal bar, the stainless steel archwire was carefully removed. Three such models were made using (1) Stainless steel (Gemini series, 3M Unitek, Monrovia, CA, USA), (2) Ceramic (InVu, TP Orthodontics, LaPorte, IN, USA) and (3) Self-ligating (Damon® SL II, Ormco, Orange, CA, USA) brackets. The elastomeric ligatures used were low-friction ligatures (Slide™, Leone SpA, Firenze, Italy) and conventional ligatures (Alastik™, 3M Unitek, Monrovia, CA, USA) (Figs 2A and B). The wires used for testing were straight lengths of 0.016” Nitinol (NiTi) and 0.019” × 0.025” stainless steel (SS). They were chosen due to their popularity and frequent use in aligning and space closure stages respectively.

Ten sample groups were made by using the following bracket-archwire combination.

1. Stainless steel brackets with conventional ligation and 0.016” NiTi (Fig. 3A).
2. Stainless steel brackets with conventional ligation and 0.019” × 0.025” SS.
3. Stainless steel brackets with low-friction ligation and 0.016” NiTi (Fig. 3B).
4. Stainless steel brackets with low-friction ligation and 0.019” × 0.025” SS.
5. Ceramic brackets with conventional ligation and 0.016” NiTi.
6. Ceramic brackets with conventional ligation and 0.019” × 0.025” SS.
7. Ceramic brackets with low-friction ligation and 0.016” NiTi.
8. Ceramic brackets with low-friction ligation and 0.019” × 0.025” SS.
9. Self-ligating brackets with 0.016” NiTi (Fig. 3C).
10. Self-ligating brackets with 0.019” × 0.025” SS.
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The brackets were ligated with either conventional or low-friction elastomeric ligatures and the tests were carried out. No prestretching of the ligatures was done. One minute was allotted for ligation of elastic ligatures, followed by a three-minute waiting period to allow a reproducible amount of stress relaxation to occur. This was followed by a friction test by using Damon self-ligating brackets. Prior to each trial, the test bracket and archwire was wiped with 95% alcohol to remove any residue and then air-dried.

Frictional force was measured using Instron universal testing machine (Model 4501, Instron USA, Norwood, MA, USA) (Figs 1A and B). The upper vice of the Instron machine engaged one end of the vertically oriented archwire, which was inserted in the bracket slots, and it pulled the archwire upwards while the lower vice of the machine held the metal bar in place. The archwires were moved through all ten brackets at a crosshead speed of 0.5 mm per minute. Once archwire movement began, each run lasted for approximately 5 minutes. The load cell registered the force levels needed to move the wire along the ten aligned brackets, and the values were transmitted to a computer. However, as minor misalignments of the brackets or nonlinearity of the wire could not be controlled, in order to estimate the extent to which the friction could be attributed to misalignment rather than ligation, a confirmatory check was performed. Each bracket-archwire combination was tested 5 times with only the terminal brackets ligated and 5 times with all brackets ligated, which yielded friction and the displacement. A randomized sequence for each type of archwire was performed. Load values were calculated in Newtons (N) and converted to grams (gm). The data was analyzed to determine which ligation methods and brackets yielded the least resistance to sliding.

All the data collected by the computer connected to the Instron machine, was transferred to Microsoft Excel 2000, where appropriate titles for archwires, brackets and trial number were placed. To find out the extent to which friction could be attributed to minor misalignments or nonlinearity of the wire that occurred while bonding the brackets on the metal rod, the data obtained for all brackets ligated was compared with the data obtained for the terminal brackets ligated using student t-test. The data was further analyzed to compare the resistance to sliding for two size archwires in relation to (a) method of ligation (b) bracket material (c) archwire size and material.

The data was grouped under 0.016" NiTi and 0.019" × 0.025" stainless steel wires. The mean and standard deviation were calculated. The mean values were compared by one-way ANOVA. Multiple range tests by Tukey-Kramer honest significant difference (HSD) procedures were employed to identify the significant groups, if p-value in one-way ANOVA is significant by using statistical software [Statistical Package for the Social Sciences (SPSS version 12.0)] for Windows. In the present study, p-value of <0.05 was considered as the level of significance.

RESULTS

On the graph, the force increases to a peak after which it falls and continues at a lower level (Graph 1). This peak denotes the static friction, i.e. the smallest force needed to initiate movement of the wire. Therefore, the highest force value recorded will be representative of the amount of static friction present.

When the data for all ten brackets ligated were compared against only the terminal brackets ligated, it was found to be statistically significantly higher (p-value <0.001) than when terminal brackets alone were ligated for all bracket-archwire combinations except for one combination. Damon SL II engaged with 0.016" NiTi archwire showed no significant difference (Table 1).

One-way ANOVA was used to compare the three factors (ligation methods, bracket materials and wires) and significance was measured using Tukey post hoc.
Method of Ligation

With 0.016” NiTi wire-stainless steel bracket combination, it was found that conventional ligation exerted considerable amount of friction than Slide and self-ligation (p < 0.001), (Table 2). The difference between Slide ligation and self-ligation was not statistically significant. Damon SL II exerted almost no force on the archwire (Graph 2).

With 0.019” × 0.025” stainless steel wire, conventional ligation exerted higher force than other two types of ligation. However, an interesting finding was that with 0.019” × 0.025” wire, slide ligature exerted less friction than Damon SL II self-ligating bracket (Graph 2). With the Tukey-HSD test, significant differences were found between conventional ligation with other two methods and no significant difference between the two (Table 2).

Bracket Material

The frictional resistance values obtained when ceramic brackets were compared with stainless steel for different ligation methods are given in Table 3.

It was found that ceramic brackets when ligated with conventional elastomeric ligatures had higher friction compared to stainless steel brackets.

With Slide ligatures also the trend remained the same. However, with Slide ligatures, ceramic brackets exhibited lower friction than with conventional ligation with both wires (Graph 3).

Slide vs Damon SL II

When Slide ligature was compared with Damon self-ligation, for 0.016” NiTi, Damon exhibited lower friction than Slide

**Table 1: Frictional forces with terminal brackets ligated and all brackets ligated**

<table>
<thead>
<tr>
<th>Archwire</th>
<th>Bracket type</th>
<th>Ligation method</th>
<th>Friction (gm) (only terminal brackets ligated)</th>
<th>Friction (gm) (all 10 brackets ligated)</th>
<th>Significance (p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.016” NiTi</td>
<td>Stainless steel</td>
<td>Conventional</td>
<td>310.000</td>
<td>1043.4</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slide</td>
<td>11.500</td>
<td>12.881</td>
<td>0.046*</td>
</tr>
<tr>
<td>Ceramic</td>
<td></td>
<td>Conventional</td>
<td>320.000</td>
<td>1206.8</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slide</td>
<td>14.200</td>
<td>15.897</td>
<td>0.017*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Damon SL II</td>
<td>10.620</td>
<td>10.948</td>
<td>0.0675 NS</td>
</tr>
<tr>
<td>0.019” × 0.025” stainless steel</td>
<td>Stainless steel</td>
<td>Conventional</td>
<td>410.400</td>
<td>1390.8</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slide</td>
<td>18.280</td>
<td>32.986</td>
<td>0.028**</td>
</tr>
<tr>
<td>Ceramic</td>
<td></td>
<td>Conventional</td>
<td>474.500</td>
<td>1634.8</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slide</td>
<td>20.500</td>
<td>44.840</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Damon</td>
<td>15.160</td>
<td>50.240</td>
<td>0.002**</td>
</tr>
</tbody>
</table>

**Note:** *Significance at 5% level; **Significance at 1% level; NS: Not significant

**Table 2: Frictional forces with three different ligation methods**

<table>
<thead>
<tr>
<th>Archwire</th>
<th>Bracket type</th>
<th>Ligation</th>
<th>Friction (gm)</th>
<th>Significance (p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.016” NiTi</td>
<td>Stainless steel</td>
<td>Conventional</td>
<td>1043.400</td>
<td>85.42</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slide</td>
<td>12.88^a</td>
<td>3.12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Damon</td>
<td>10.94^a</td>
<td>1.037</td>
</tr>
<tr>
<td>0.019” × 0.025” stainless steel</td>
<td>Stainless steel</td>
<td>Conventional</td>
<td>1390.800</td>
<td>142.77</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slide</td>
<td>32.98^a</td>
<td>5.767</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Damon</td>
<td>50.24^a</td>
<td>2.145</td>
</tr>
</tbody>
</table>

**Note:** ^Statistically significant at 1% level; Different alphabets between groups indicate significance at 5% level

**Table 3: Frictional forces with different bracket materials**

<table>
<thead>
<tr>
<th>Archwire</th>
<th>Ligation</th>
<th>Bracket type</th>
<th>Friction (gm)</th>
<th>Significance (p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.016” NiTi</td>
<td>Conventional</td>
<td>Stainless steel</td>
<td>1043.4</td>
<td>85.42</td>
</tr>
<tr>
<td></td>
<td>Slide</td>
<td>Ceramic</td>
<td>1206.8</td>
<td>76.28</td>
</tr>
<tr>
<td></td>
<td>Stainless steel</td>
<td>Ceramic</td>
<td>12.88</td>
<td>3.12</td>
</tr>
<tr>
<td>0.019” × 0.025” stainless steel</td>
<td>Conventional</td>
<td>Ceramic</td>
<td>1634.8</td>
<td>184.94</td>
</tr>
<tr>
<td></td>
<td>Slide</td>
<td>Stainless steel</td>
<td>32.98</td>
<td>2.84</td>
</tr>
<tr>
<td></td>
<td>Ceramic</td>
<td>44.84</td>
<td>5.76</td>
<td></td>
</tr>
</tbody>
</table>

**Note:** *Statistically significant at 5%; **Statistically significant at 1%
Table 4: Frictional forces with Slide and Damon self-ligation methods

<table>
<thead>
<tr>
<th>Archwire</th>
<th>Ligation</th>
<th>Friction (gm)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.016&quot; NiTi</td>
<td>Slide</td>
<td>12.88</td>
<td>3.123 NS</td>
</tr>
<tr>
<td></td>
<td>Damon</td>
<td>10.95</td>
<td>1.037</td>
</tr>
<tr>
<td>0.019 × 0.025&quot;</td>
<td>Slide</td>
<td>32.98</td>
<td>2.884 0.033*</td>
</tr>
<tr>
<td>stainless steel</td>
<td>Damon</td>
<td>50.24</td>
<td>2.145</td>
</tr>
</tbody>
</table>

*Statistically significant at 5%; NS: Not significant

DISCUSSION

Sliding mechanics is commonly employed in orthodontics for effecting closure of extraction spaces, distalization of teeth, eruption of high cuspids, correction of rotations, and leveling and aligning of teeth. Frictional forces developing between the bracket and archwire opposes such movements. Up to 60% of the applied force is dissipated as friction, which reduces the force available for tooth movement. High levels of bracket-archwire friction may result in binding of the bracket accompanied by little or no tooth movement.

This higher frictional resistance requires an increase in the magnitude of orthodontic forces needed to overcome the friction, yet have enough residual force for optimal tooth movement. Therefore, orthodontists are always seeking techniques to minimize or even eliminate friction. In addition, as a result of appliance inefficiency and friction, it is difficult to determine and control the magnitude of force that is being received by the individual tooth.

The experimental design used in this study consisted of ten brackets aligned on a metal rod. Frictional resistance increases as the number of brackets included in the assembly increases. Therefore, the ten bracket model provides a more realistic vision of friction than a model involving single bracket or a quadrant.

In the present study, when the data for all ten brackets ligated were compared against only the terminal brackets ligated, it was found to be statistically significantly higher than when terminal brackets alone were ligated for all bracket-archwire combinations. This indicated that the higher values obtained when all ten brackets were ligated were due to the forces of ligation.

Only one bracket-archwire combination bracket, Damon SL II self-ligating bracket 0.016" NiTi wire combination showed statistically insignificant difference in both conditions. The low-friction related to the Damon SL II bracket reflects the lack of normal force levels in these brackets.

Three different ligation methods were compared with each other using ANOVA followed by Tukey-Kramer HSD analysis for comparison between the groups. Of the three types of ligation methods compared, with 0.016" NiTi, conventional ligation exhibited higher friction (p < 0.001) than other methods. Both low-friction ligation and self-ligation showed significantly lower levels of friction. The significant difference between conventional ligation and self-ligation are similar to those reported by Pizzoni et al and Thomas et al. The difference between Slide and Damon SL II ligation systems were insignificant. When combined with 0.019" × 0.025" stainless-steel wire also conventional ligation exhibited higher friction. But with 0.019" × 0.025" stainless steel wire, Slide ligatures showed less friction than the Damon system. This probably shows that Damon SL II system has lower friction only when used with wires of lower diameter.
Ceramic brackets generated more friction than the stainless steel brackets with both stainless steel and NiTi wires. This is most likely due to the increased roughness and porosity of the ceramic surface and a sharp bracket slot edge, thus, resulting in a higher coefficient of friction. This is in agreement with the study of Loftus et al. who showed that ceramic brackets generated higher friction than stainless steel.

When compared to conventional ligation, Slide ligatures were able to reduce the friction of ceramic brackets. The presence of low-friction ligatures enables ceramic brackets to release a significant amount of orthodontic force during sliding, very similar to stainless steel brackets.

When Slide was compared with Damon system, for small round NiTi wires, Damon showed lower frictional value (although it was not statistically significant). However, with larger stainless steel wires, Damon showed higher friction than Slide low-friction ligatures.

**Clinical Implications**

Frictional demands during orthodontic treatment vary with the stage of the treatment. It is highly desirable to have minimum friction during the aligning and space closure stages of treatment and greater friction in later stages. Previous studies have proven that conventional ligation exerts very high amounts of normal force on the bracket-archwire interface leading to higher friction. The solution to reduce friction is the use of self-ligating brackets which exert very minimal normal force. But, they have associated problems as well, particularly higher cost involved when compared to conventional brackets and reduced control over tooth movements.

Low-friction therefore is suggested as a practical alternative between conventional ligation and self-ligation. Slide ligature is a valuable and economically viable alternative to Damon self-ligating bracket in that it provides comparable amount of friction as Damon when low-friction is required and gives the option of using conventional or steel ligatures when higher friction is required in the latter stages of treatment at a fraction of the cost of self-ligating brackets. The frictional needs of specific cases should be evaluated early in treatment and conventional or low-friction ligatures can be applied depending on the plan. As it also reduces the friction when used in conjunction with ceramic brackets, the use of low-friction ligatures allows the orthodontist to realize the clinical advantages of low-friction biomechanics to those in the use of esthetic ceramic brackets.

**SUMMARY AND CONCLUSION**

This study compared the frictional resistance of Slide low-friction ligation with conventional and self-ligation methods and with ceramic and stainless steel brackets. The maximum amount of force recorded while drawing the archwire through the ligated brackets was considered as the static friction for the archwire-bracket couple. Conventional ligation exhibited higher friction than low-friction and self-ligation methods with all the archwire-bracket combinations. Damon self-ligating system exhibited less friction than low-friction ligation with lower archwires and higher friction with higher archwires. Slide low-friction ligatures were able to reduce the friction of ceramic brackets in a similar way to stainless steel brackets.

**REFERENCES**