Force Decay of Elastomeric Ligatures: Influence on Unloading Force Compared to Self-Ligation

Alan Petersen; Sheldon Rosenstein; Ki Beom Kim; Heidi Israel

ABSTRACT

Objective: To compare elastomeric ligatures (EL) vs self-ligating (SL) brackets in terms of their effects on the unloading force of a 0.014-inch CuNiTi aligning wire.

Materials and Methods: By simulating the alignment of a lingually malposed canine and using a full-arch design, three ligation methods—SL, EL, and "relaxed" elastomeric ligature (REL)—were tested with 30 wires per group. Each test was conducted in a dry field within a Plexiglas case at 35 ± 2°C. Eleven brackets were affixed from first molar to first molar site on a steel plate with a space created at the location of the left canine. The wire was deflected 3 mm then was unloaded at a speed of 2 mm per minute. Data were gathered from four points along the unloading plot generated during each test and then were compared by using the Kruskal-Wallis one-way analysis of variance. Mann-Whitney tests were used to compare combinations of groups.

Results: Wires ligated with EL and REL produced an average unloading force equal to 56% and 88%, respectively, of the same wire in an SL bracket.

Conclusions: The unloading forces produced by a wire after force decay of the elastomers are not statistically different from the forces present in self-ligating systems. (Angle Orthod. 2009;79: 934–938.)

KEY WORDS: Elastomeric; Force decay; Self-ligation

INTRODUCTION

Studies have evaluated the influences of bracket slot, wire, ligation, a wet (vs dry) field, and extraneous forces on friction resistance.1–4 Typically, direct frictional resistance measurements have been obtained by drawing a wire through a single bracket or a series of brackets.5,6 Friction has also been examined indirectly by measuring the reduction in spring back force that is produced.7 Self-ligating brackets generally show less frictional resistance than is exhibited by conventional ligating brackets.8,9

In each of these studies, when conventional elastomeric ties were used as the ligation method, the ties were placed immediately before the test was performed, with no exposure to a simulated oral environment.1–7 This is an important distinction when elastic modules and their contribution to friction are considered. Taloumis et al8 stretched elastomers over a stainless steel dowel 0.155 inches in diameter to simulate the stretch necessary to apply an elastomeric ligature over a maxillary central incisor twin bracket. The ligatures then were immersed in an artificial saliva bath for varying periods of time. After 1 month, the elastomers showed a decrease in force of 42% to 66%. It was demonstrated that after only 24 hours, the amount of force decay of elastomeric ligatures ranged from 80.7% to 89.1% of the total force lost after 28 days. These results show that elastomeric ligatures are affected by moisture and heat, exhibit rapid force loss, and deform permanently when stretched.10

The purpose of this study was to examine how force decay of elastomeric ligatures affects the unloading force of a superelastic wire and, specifically, how that force relates to reports in previous studies that compared self-ligation vs conventional ligation.
MATERIALS AND METHODS

Archform Model Design

An archform model was fabricated from a ½-inch-thick tool-steel plate (Figure 1). The concave shape of the archform matches the shape of the small, maxillary Tru Arch archform (Ormco Corp, Glendora, Calif). Nine In-Ovation R (GAC, Bohemia, NY) maxillary brackets (0.022 × 0.028-inch slots), and two molar tubes were bonded with Transbond XT (3M/Unitek, Monrovia, Calif) to the archform model, from second premolar to second premolar, except at the right canine site. A 0.021 × 0.025-inch stainless steel archwire was bent to the same shape as the archform and was engaged in the slots while the adhesive cured to allow for relative vertical leveling of the brackets. At the right canine site, material was cut from the archform model, allowing space for the probe to effect a lingual deflection of the archwire (Figure 1).

Sample Testing

One round wire (0.014-inch) was selected from which unloading force deflection patterns could be generated. This was a 27 degree CuNiTi wire (Ormco Corp, Glendora, Calif), which served as the maxillary small Tru Arch archform. Ninety wires obtained from the vendor without bias were divided into three groups of 30 for testing. One group of wires was tested with the In-Ovation R self-ligation brackets. The clips then were removed from the brackets. The second group was ligated with elastomerics (#361-080) (TP Orthodontics, Inc, La Porte, Ind) placed with the TP Straight Shooter (TP Orthodontics) to maintain the consistency of pre-stretch. The third group was ligated with "relaxed" elastomerics. Approximately 350 elastomerics were placed over a 0.155-inch-diameter steel rod by rolling them over a tapered end. The rods were placed in a 35°C water bath for 48 hours to simulate the oral environment then were placed with the TP Straight Shooter.

Testing was carried out with a universal testing machine (Model 1011, Instron Corp, Canton, Mass). An x-y recorder was electronically connected to the testing machine to record the test data on plot paper (Figure 2).

The archform model was mounted onto a base plate, which was centered and attached to the fixed
Table 1. Means and Standard Deviations of Aligning Forces (grams) from the Test Groups at Four Deflections of .014 CuNiTi (N = 90) *

<table>
<thead>
<tr>
<th>Deflection</th>
<th>Ligation</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5 mm</td>
<td>Self-ligated</td>
<td>158.47</td>
<td>4.66</td>
</tr>
<tr>
<td></td>
<td>Elastomeric</td>
<td>77.13</td>
<td>10.99</td>
</tr>
<tr>
<td></td>
<td>“Relaxed” elastomeric</td>
<td>132.00</td>
<td>8.13</td>
</tr>
<tr>
<td>2.0 mm</td>
<td>Self-ligated</td>
<td>134.43</td>
<td>5.85</td>
</tr>
<tr>
<td></td>
<td>Elastomeric</td>
<td>63.43</td>
<td>9.23</td>
</tr>
<tr>
<td></td>
<td>“Relaxed” elastomeric</td>
<td>108.00</td>
<td>8.04</td>
</tr>
<tr>
<td>1.5 mm</td>
<td>Self-ligated</td>
<td>125.23</td>
<td>3.54</td>
</tr>
<tr>
<td></td>
<td>Elastomeric</td>
<td>67.47</td>
<td>7.76</td>
</tr>
<tr>
<td></td>
<td>“Relaxed” elastomeric</td>
<td>104.97</td>
<td>8.19</td>
</tr>
<tr>
<td>1.0 mm</td>
<td>Self-ligated</td>
<td>94.07</td>
<td>4.18</td>
</tr>
<tr>
<td></td>
<td>Elastomeric</td>
<td>76.30</td>
<td>6.78</td>
</tr>
<tr>
<td></td>
<td>“Relaxed” elastomeric</td>
<td>103.33</td>
<td>7.86</td>
</tr>
</tbody>
</table>

* Mann-Whitney post hoc tests showed a significant difference (P < .05) in each group at each deflection point.

Table 2. Marginal Means (grams): Average Force Value Over Measured Deflection Points

<table>
<thead>
<tr>
<th>Groups</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-ligation</td>
<td>128</td>
</tr>
<tr>
<td>Elastomeric ligation</td>
<td>71</td>
</tr>
<tr>
<td>Relaxed elastomeric</td>
<td>112</td>
</tr>
</tbody>
</table>

Kruskal-Wallis test revealed significant differences at each deflection point. Subsequent Mann-Whitney post hoc tests showed that each group was significantly different from the others at every deflection point.

The average unloading force for the self-ligating group over the deflection was 128 g (Table 2). The corresponding averages of the relaxed ligature and fresh ligature groups were 112 g and 71 g, respectively. The highest aligning forces were produced in the self-ligating group at all deflection points with a single exception; at 1 mm of deflection, the relaxed ligature group averaged 103 g of unloading force compared with 94 g for the self-ligating group. Each of the wires tested returned to its original passive shape.

**DISCUSSION**

The force decay of the elastomeric ligatures significantly altered the magnitude of the unloading forces. This is explained by the reduction in the normal force delivered from the wire to the bracket slot via relaxation of the elastomer. As the normal force decreases, a corresponding decrease in frictional resistance occurs. This frictional resistance “eats up” the stored energy in the deflected archwire. When compared with fresh elastomeric ties, the relaxed group showed a greater than 50% increase in the aligning force generated from a .014 CuNiTi wire. The plot of the unloading forces shows that the relaxed group more closely approximates the self-ligating group than it does the immediately tied group (Figure 3).
Many studies have compared the self-ligating appliance vs conventional ligation. All of these studies have shown that the self-ligating system produces a dramatic decrease in frictional resistance or, rather, a dramatic increase in aligning forces.\textsuperscript{11–15} Each of these studies failed to consider the effect of force decay of the elastomeric ligatures. However, these results have been used by some to support claims that low-friction orthodontics results in more efficient treatment.\textsuperscript{16} Other studies have shown no such increase in efficiency.\textsuperscript{17,18}

From these studies,\textsuperscript{11–15} it is clear that self-ligating brackets result in less frictional resistance. However, it must be noted that in each and every instance when the unloading or aligning forces have been measured, the self-ligating systems produced greater forces. Common today in discussions of self-ligating appliances is the expression, “low-friction, low-force orthodontics.” In fact, this study has shown convincingly that this phrase is erroneous. Schumacher et al\textsuperscript{7} studied the deactivation of a group of leveling archwires. During deactivation, a dramatic decrease in the force necessary to level was observed as the result of friction between the archwire and the bracket slots. Investigators found that up to 50% of the local force to align was “lost” owing to this frictional resistance between the archwire, bracket, and ligation. This means that if frictional resistance is reduced, the resultant unloading force will be greater, not lesser. This was true for both the self-ligating group and the relaxed group in comparison with the immediately tied group.

The average unloading force over the deflection points was only 16 g less for the relaxed group vs the self-ligated group. Proffit\textsuperscript{19} reported that the optimum forces required to produce tipping, root uprighting, rotation, extrusion, and intrusion—all of the movements seen in leveling and aligning—are between 10 and 100 g. A recent meta-analysis, which reviewed more than 400 human and animal studies, did not produce enough evidence to support any statement about the optimal force for tooth movement.\textsuperscript{20} Studies have reported the optimal tooth moving force to range from 2 to 20 KPa.\textsuperscript{21} Animal research studies reviewed indicated that a large range of force magnitudes produced approximately the same displacement rates as were produced by tooth movement.\textsuperscript{21} As to whether the force magnitudes reported in the present study are optimum for leveling and aligning teeth, a determination cannot be made, but a 16 g of force difference has been noted when the range of forces reported for tooth movement is considered. This includes the differences found at 1 mm of deflection. At this deflection, the relaxed group produced an unloading force 9 g greater than the self-ligating group. This was a small difference, and why it occurred is not known. As was stated previously, the wide range of tooth movement forces reported\textsuperscript{19–21} would lead to the conclusion that this difference is clinically not significant. What is of greater interest is that the range of forces over the deflection in the self-ligating groups was greater than 60 g, and the range for the relaxed group was only 29 g.

CONCLUSIONS

- Force decay of elastomeric ties results in increased aligning forces when compared with fresh elastomers.
- The unloading forces produced by a wire after force decay of the elastomers are not statistically different from the forces present in self-ligating systems.
- Self-ligating brackets and relaxed elastomers create a system of greater aligning forces when compared with fresh elastomers.

REFERENCES

11. Bunkall D. Center for Advanced Dental Education. The Effect of Extraneous Forces Upon the Frictional Characteristics of Self-Ligating Orthodontic Brackets and Nickel-Tita-
nium Archwires Utilizing a Novel In Vitro Model. St Louis, Mo: Saint Louis University; 2006.


