Original Article

A comparison of resistance to sliding of self-ligating brackets under an increasing applied moment

Benjamin T. Pliska^a; John P. Beyer^b; Brent E. Larson^c

ABSTRACT

Objective: To test the null hypotheses that at clinically relevant amounts of applied moment, there are no differences in the amount of resistance to sliding (RS) between self-ligating (SL) and conventionally ligated (CL) brackets on both stainless steel (SS) and nickel-titanium (NT) archwire. **Materials and Methods:** Three different SL brackets and one CL bracket, all 0.022" slot, were tested on a custom-built device to simulate canine retraction mechanics in the second-order dimension. The setup allowed for simultaneous and continuous measurement of RS and applied moment at the bracket-archwire interface. The brackets tested were Damon3, In-Ovation R, Smartclip, and Victory, all of which were tested with 0.019" \times 0.025" SS and NT archwires. The RS at calculated moments of 2000 g-mm and 4000 g-mm was determined and compared between the various brackets and both archwire types. Descriptive measures, analysis of variance, and Tukey-Kramer post-test comparisons were used to calculate results.

Results: All brackets displayed a greater amount of RS with NT than with SS archwires. At the higher moment levels (4000 g-mm), no significant reduction in RS was found between CL and SL brackets on both SS and NT archwires. At lower levels of applied moment (2000 g-mm), reductions in RS of 18% (42.7 g) and 18% (38.5 g) were found between the CL bracket and the best performing SL bracket on NT and SS, respectively.

Conclusion: At low values of applied moment, some statistical differences were found; however, in general, the differences in RS amongst the various SL and CL brackets tested may not be clinically relevant. (*Angle Orthod.* 2011;81:794–799.)

KEY WORDS: Friction; Self-ligating; Resistance to sliding

INTRODUCTION

Contemporary fixed orthodontic treatment involves movement of a bracket along an archwire. All such movements resulting in the contact of any two objects involve friction, thereby causing a resistance to sliding

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(RS).¹ Whether it is the initial unraveling of crowding or the sliding mechanics of space closure, friction is unavoidable in orthodontics. In the hopes of reducing patient discomfort and treatment time and improving efficiency of orthodontic tooth movement, several attempts have been made to reduce the friction involved in sliding mechanics. These include modifications of bracket² and archwire materials,³ the addition of coatings or other treatment of material surfaces,⁴ alterations in the geometry of the bracket slot,^{4,5} or the use of novel designs of elastomeric ligatures.⁶ Currently one of the most heavily commercially advertised methods of reducing friction is the use of self-ligating (SL) brackets.

There is a large body of research examining the RS of SL brackets in terms of bracket and wire material, dimensional and environmental variables, and mode of ligation.⁷ In the evaluation of frictional studies, a clear understanding of the variables involved is required. As described by Kusy and Whitley,⁸ in the absence of extreme forces that cause physical notching of the archwire, the RS of a bracket along an archwire arises

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Table 1. Bracket and Archwire Materials Tested

Brackets (0.022" Upper Left Canine) ^a	Archwires (0.019" $ imes$ 0.025")
Damon3 (Ormco Corporation, Glendora, CA) (SL) In-Ovation-R (Dentsply GAC Intl Inc, Bohemia, NY) (SL)	Stainless steel (Dentsply GAC Intl Inc, Bohemia, NY)
Smartclip (3M Unitek, Monrovia, CA) (SL) Victory (3M Unitek, Monrovia, CA) (CL)	Nickel titanium (Highland Metals Inc, San Jose, CA)

^a SL indicates self-ligated; CL, conventionally ligated.

from two sources: (1) the force of ligation (friction in the first-order dimension) and (2) the force of binding (friction in the second-order dimension) between the archwire and bracket slot. When clearance exists between the archwire and bracket slot (passive configuration),⁹ the force of ligation makes the largest contribution to RS.¹⁰ The literature predictably demonstrates through lab studies that the use of SL brackets, which minimize the normal force of ligation.^{2,11-14}

However, experimental models testing brackets in a passive configuration or with fixed or immovable test brackets may have limited clinical relevance. Clinically, as forces are applied to teeth, moments are generated that immediately tip and rotate teeth within the periodontal ligament space until contacts are formed between the bracket and archwire.^{15–18} As the moment and force of binding between the bracket slot and archwire increase, the relative contribution of ligation to RS decreases to the point where frictional resistance is dominated by this binding.^{10,19} Despite this fact, few publications have evaluated SL brackets in what could be classified as the active state, with a movable or dynamic bracket-archwire interface. It follows, then, that a study in which a bracket is gradually tipped, allowing the bracket-archwire interface to bind, would be a more appropriate in vitro study of RS.

For this study, three commercially available SL brackets, along with a conventionally ligated (CL) (ie, elastomeric) bracket, were mounted on a testing apparatus to simulate canine retraction using sliding mechanics and the application of a moment. The RS was related to the magnitude of moment applied with two different types of archwire. This study's purpose was to test the hypothesis that, at clinically relevant amounts of applied moment, there are no differences in the RS between SL and CL brackets on both stainless steel (SS) and nickel-titanium (NT) archwire.

MATERIALS AND METHODS

Details of the brackets and archwires used in this study can be found in Table 1. Each archwire-bracket combination was tested 10 times, with a virgin bracket and archwire used for each sample run. All archwire and bracket materials were donated by the manufacturers for this study.

The brackets were mounted to the center of acrylic sleeves and aligned with the rotational axis of the testing apparatus using a precision-machined mounting jig. The sample brackets were then bonded to the acrylic sleeves using Transbond XT (3M Unitek, Monrovia, Calif), with the surfaces of the bracket base and sleeve completely separated by the bonding material. In this way the builtin prescription of the different brackets could be effectively removed, ensuring that the bracket slots and the sample archwires were collinear. The apparatus was then transferred to a mounted table on a universal testing machine (Instron Corporation, Model 4204, Canton, Mass) and centered on the Instron actuator stroke axis. To simulate the adjacent brackets during canine retraction, two nylon rollers were mounted to the testing table at a distance of 10 mm above and 8 mm below the apparatus' axis of rotation.

The acrylic sleeves with attached sample brackets were placed on the machine axle, and the sample archwire was suspended from a 1000-g load cell attached to the crosshead of the universal testing machine. The archwire was then placed into the slot of the bracket to be tested and ligated with either the clip or door of the SL brackets, or with an elastomeric tie for the CL brackets. The Victory (CL) brackets had their archwire samples ligated at least 36 hours prior to testing to allow the elastic material to stabilize.²⁰ Positioned lateral to the archwire/bracket setup was a second 2000-g load cell, which was attached to the axle of the test machine. This load cell was mounted to a movable table, which allowed horizontal displacement via manual rotation of a positioning knob. As the load cell was translated horizontally, the motor axle and sample bracket were rotated, resulting in application of a moment to the archwire (Figure 1). The archwire samples were pulled vertically through the bracket slot by the crosshead of the universal testing machine at velocity of 5 mm/min. To eliminate the effects of wear, a virgin archwire and bracket were used for each sample; the various brackets were tested in random order.

The tensile forces required to both move the wire vertically through the bracket slot as well as to rotate the bracket were transmitted from the corresponding load cells and a signal conditioner (Model GM, Honeywell Sensotec, Columbus, Ohio) to an active data recorder and LabTech Notebook data acquisition and process control computer software (4/94 Release,

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Figure 1. The bracket-archwire assembly. A lateral force (F) rotates the axle and mounted bracket, while the archwire is pulled vertically through the bracket by the crosshead of the Instron machine. The lateral force rotating the bracket and the force required to pull the archwire (RS) were recorded simultaneously. The moment (M) applied to the bracket was calculated as $M = F \times d$. A 0.019" \times 0.025" NT archwire/Victory bracket couple at the end of a test run is shown.

Laboratory Technologies Corporation, Wilmington, Mass). The data were stored, exported as an ASCII file, and then imported into Microsoft Excel (Redmond, Wash) for analysis.

Statistical Analysis

The tensile reading from the lateral load cell was converted to a moment by multiplying the value by the perpendicular distance from the point of force application to the center of rotation. For this experimental setup, this corresponded to the radius of the test machine axle. The recorded frictional data was plotted against this calculated moment for each test run. A line of best fit was then applied to the plotted data, which was then used to calculate the RS at moments of 2000 g-mm and 4000 g-mm. The values from the 10 sample runs were then averaged for each bracket and archwire combination. Assuming a distance of 10 mm for a bracket to the center of resistance for a maxillary canine, these moments would correspond to retraction forces of 200 g and 400 g, respectively. These moments were selected as being representative of low-end and high-end levels of force used clinically to retract canines with sliding mechanics.^{21,22}

Descriptive measures including means and standard deviations, one-way analysis of variance (P < .05), and Tukey-Kramer post-test comparisons were used to calculate the means and statistical differences among the different samples.

RESULTS

Means and standard deviations of RS for each bracket tested on SS and NT archwires are presented in Figures 2 and 3, respectively.

With a SS archwire at a calculated moment of 2000 g-mm, the RS among the brackets tested had a range of 38.5 g. The two passive SL brackets (Damon3 and Smartclip) displayed statistically less friction (P < .05) than the CL bracket (Victory) at this force and archwire combination. At the higher force level (4000 g-mm) on the SS archwire, the range of RS was 30.8 g between the brackets tested; however, the differences were not statistically significant (P < .05).

When NT archwire was tested, all brackets displayed greater levels of RS compared to SS (P < .05) at both levels of moment examined. The range of RS values with NT archwire at 2000 g-mm was 74.5 g, with the CL bracket (Victory) performing better than the active SL (In-Ovation) bracket. The passive SL brackets displayed less RS than the CL bracket, with the greatest difference being 42.7 g. This difference was found to be statistically significant (P < .05). At 4000 g-mm, the CL bracket did not display significantly (P < .05) more RS than the SL brackets tested. In fact, the CL bracket performed better than two of the SL designs.

DISCUSSION

The present study compared the RS of simulated canine retraction with one CL and three different SL brackets under the application of an increasing moment in the second-order dimension. With this novel testing design, no statistical differences were found among the various bracket designs when higher (400 g) but very typical force levels were used. This parity among brackets was observed with both SS and NT archwires. At the lower level of force (200 g) examined, reductions in RS of 18% (38.5 g) and 18% (42.7 g) were found between the CL and the best performing SL bracket on SS and NT archwires, respectively. This demonstrates that during sliding mechanics, especially when moderate levels of force are used, the friction induced by ligation has little influence on the overall RS.

With each bracket and archwire combination tested in the current study, the amount of RS increased with increasing moment applied to the bracket. This finding is in agreement with several earlier studies, where RS was greater when the normal force of binding at the archwire-bracket couple was increased.^{17,23,24} The results clearly show the importance of understanding the interplay between the force of ligation and active binding between a bracket and archwire and their relative contributions to RS in sliding mechanics. This



Figure 2. Resistance to sliding on 0.019" \times 0.025" SS archwire.

relationship has been examined in several ways. Numerous studies have compared the frictional resistance between brackets with different modes of ligation when rigid, immovable, and often perfectly aligned brackets have been used.^{2,4,6,12,14} In such situations, active binding will make little to no contribution to RS. Therefore, limiting the force of contact between an archwire and a bracket slot through the use of a metal clip/door or novel elastic module would logically lower frictional resistance. However, such instances where the bracket cannot freely tip relative to the archwire may be of little clinical relevance. Whenever a force is applied to a tooth away from the center of resistance, the tooth will tip as a moment is created. This tipping will cause binding between the bracket slot and archwire, which guickly overwhelms the contribution of mode of ligation to RS.25

Similar to the current study, investigations that have accounted for the clinical effects of a tooth tipping relative to the archwire under an applied force typically show less improvement in frictional resistance through the use of SL brackets. Bednar et al.¹⁵ applied a moment to brackets via a suspended weight and observed no differences in frictional force between SL and CL bracket designs undergoing simulated canine retraction. Also, Loftus et al.,²⁶ in a dynamic model that allowed rotation as well as second-order tipping of teeth during simulated sliding mechanics, found no significant differences among CL and SL brackets. Other investigations have failed to find differences in RS between SL and CL brackets with increasing amounts of angulation²⁷ or with second-order deflection,²⁸ or when larger archwires²⁹ were used.

The limited influence that the force of ligation has on RS when the bracket is in an active binding situation may explain why recent clinical studies have failed to find differences in the rate of alignment between SL and CL bracket designs. Both the Damon bracket^{30,31} and the Smartclip bracket³² have been found to be no more effective than CL twin brackets at reducing irregularity during the initial stage of treatment. Additionally, Miles³³ found no advantages with the use of the Smartclip during en masse space closure.

In the present study RS was greater when sliding on NT compared to SS archwires with each bracket tested. Some previous investigations have found greater frictional resistance with SS^{19,34}; however, this contradiction is most likely a result of differences in



Figure 3. Resistance to sliding on 0.019" \times 0.025" NT archwire.

experimental design. In studies with testing models that featured a bracket that was free to tip and bind the archwire, RS on NT archwire was shown to be greater than^{23,24} or similar to²⁶ RS on SS archwire.

This investigation was performed under the conditions of an applied moment in an attempt to simulate one aspect of the clinical setting; however, it is limited to a frictional analysis in the second-order plane. The results of this study suggest that future in vitro comparisons of various bracket designs should be performed dynamically, with brackets that are able to tip freely and engage the archwire, to better represent the complex and dynamic three-dimensional environment of the patient.

CONCLUSION

- All brackets tested displayed a greater amount of RS with NT archwires than with SS archwires.
- At clinically relevant amounts of applied moment, the difference in total RS among the various SL and CL brackets tested was not clinically significant.
- The results of this study suggest that, in clinical conditions, a dramatic reduction in RS should not be expected with the use of SL brackets.

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