



Virginia Commonwealth University  
**VCU Scholars Compass**

---

Theses and Dissertations

Graduate School

---

2015

# IN-VITRO ASSESSMENT OF A NOVEL BRACKET'S EFFECT ON RESISTANCE TO SLIDING

James Blackburn

*Virginia Commonwealth University*, [blackburnj2@vcu.edu](mailto:blackburnj2@vcu.edu)

Follow this and additional works at: <http://scholarscompass.vcu.edu/etd>

 Part of the [Orthodontics and Orthodontology Commons](#)

© The Author

---

Downloaded from

<http://scholarscompass.vcu.edu/etd/3722>

This Thesis is brought to you for free and open access by the Graduate School at VCU Scholars Compass. It has been accepted for inclusion in Theses and Dissertations by an authorized administrator of VCU Scholars Compass. For more information, please contact [libcompass@vcu.edu](mailto:libcompass@vcu.edu).

©JAMES NEWELL BLACKBURN 2015  
ALL RIGHTS RESERVED

# **IN-VITRO ASSESSMENT OF A NOVEL BRACKET'S EFFECT ON RESISTANCE TO SLIDING**

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science  
in Dentistry at Virginia Commonwealth University.

by

James Newell Blackburn

B.S. in Biology from Brigham Young University, April 2009

D.D.S. from University of California, Los Angeles, June 2013

Director: Dr. Eser Tüfekçi, D.D.S., M.S., Ph.D., M.S.H.A.

Associate Professor, Department of Orthodontics

Virginia Commonwealth University

Richmond, Virginia

May 2015

## Acknowledgment

I would like to thank Dr. Eser Tüfekçi for the enormous amount of direction and guidance she offered in designing and carrying out this research project. She was instrumental in every stage of the project design and invaluable when it came to writing and editing my thesis. I always appreciated Dr. Tüfekçi giving me her full attention, even when I would interrupt her busy schedule for help with my research. I would like to acknowledge Drs. Shroff and Lindauer for their help and input along the way as well as leading an exceptional residency program. I considerate it a privilege and honor to have studied and trained under the full-time faculty at VCU Orthodontics and will forever be proud of my association with the program.

I would also like to thank Dr. Mustafa Ergun for his engineering expertise throughout this project without which I would have made many errors. The VCU Mechanical Engineering department, especially Dr. Charles Cartin, were also invaluable and I would like to thank them for providing the facilities to test our hypothesis. I extend my gratitude to Dr. Ahmad Hamdan of the University of Jordan for his help in securing the measuring jig and to Dr. Peter Rock and Ted Harrington of the School of Dentistry, University of Birmingham UK for manufacturing and providing instruction on the testing jig.

I would also like to thank the co-residents I have had while at VCU who have become some of the best friends I will ever have. I admire each of them and am grateful for the lifelong friendships we have established.

Finally, and most importantly, I would like to recognize my family. Thank you to my mom for her never-ending encouragement and to my dad for being the most brilliant person I know and for always being there to answer my questions. I'm especially grateful to my wife and best friend, Gloria, for being so understanding through everything. She is truly the reason I do what I do.

## Table of Contents

List of Tables .....	iv
List of Figures .....	v
Abstract.....	vi
Introduction .....	1
Materials and Methods.....	5
Results .....	8
Discussion .....	10
Conclusion.....	14
Figures .....	15
Tables.....	23
References.....	24
Vita .....	28

## List of Tables

Table 1: Average resistance to sliding for 0, 2, 4, 6, and 8° of tip (newtons). *P <0.05 when compared to 3M bracket.....	23
Table 2: Average resistance to sliding for 0, 2, 4, 6, and 8° of tip (grams) .....	23

## List of Figures

Figure 1: (a) Victory Series bracket, 3M Unitek; (b) Damon Q bracket, Ormco; (c) In-Ovation R bracket, GAC Dentsply.....	15
Figure 2: The novel bracket design including an exploded view (lower right) .....	15
Figure 3: Magnified version of traditional bracket/wire contact and novel bracket/wire contact....	16
Figure 4: The testing jig mounted onto the MTS Insight 30 testing machine.....	17
Figure 5: The testing jig with the wire loop placed below the bracket being tested .....	18
Figure 6: Sample data from the MTS Insight 30 testing machine.....	19
Figure 7: Average resistance to sliding for the tested brackets at 0° of tip. *P <0.05 when compared to 3M bracket.....	19
Figure 8: Average resistance to sliding for the 3M bracket at 0, 2, 4, 6, and 8° of tip.....	20
Figure 9: Average resistance to sliding for the Damon bracket at 0, 2, 4, 6, and 8° of tip .....	20
Figure 10: Average resistance to sliding for the In-Ovation bracket at 0, 2, 4, 6, and 8° of tip .....	21
Figure 11: Average resistance to sliding for the Novel Bracket at 0, 2, 4, 6, and 8° of tip.....	21
Figure 12: Average resistance to sliding for the tested brackets at 2, 4, 6, and 8° of tip.....	22

## Abstract

### IN-VITRO ASSESSMENT OF A NOVEL BRACKET'S EFFECT ON RESISTANCE TO SLIDING

by James N. Blackburn, D.D.S.

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry at Virginia Commonwealth University.

Virginia Commonwealth University, 2015

Thesis Director: Eser Tüfekçi, D.D.S., M.S., Ph. D., M.S.H.A.  
Associate Professor, Department of Orthodontics

Friction, binding and notching are the factors that contribute to resistance to sliding during orthodontic tooth movement. However, most attempts at reducing resistance aim only to reduce the archwire/ligature friction. In this study, a novel bracket with a unique design aimed to reduce all three components of resistance to sliding. Four types of brackets (passive and active self-ligating, traditionally ligated and the novel bracket, (n=5, each) were tested at 0, 2, 4, 6, and 8° of tip on a 0.019 x 0.025" archwire. The resistance to sliding values were recorded. At 0°, the passive self-ligating and novel bracket showed reduced resistance when compared to the traditionally ligated bracket (P< 0.05). At the other angles of tip, no differences were observed among the brackets. These data suggest that the novel bracket could potentially decrease the resistance to sliding during orthodontic treatment and further studies are indicated to test the improved bracket design.



## Introduction

The innate foundation of edgewise orthodontics is based on the interaction between the archwire and the bracket. In an ideal environment, any force applied to an orthodontic bracket would be perfectly transferred to the tooth. However, the interactions between the bracket and the archwire are less than ideal due to resistant forces. Montasser et al.<sup>1</sup> reported that typical force loss due to resistance to sliding during canine retraction with a 0.022" slot sized bracket on a 0.019 x 0.025" is between 35% and 74% of the applied force depending on the type of bracket and archwire material used. Another study by Yanase et al.<sup>2</sup> found that the amount of applied force lost due to resistance to sliding can be greater than 50%. Additionally Kusy and Whitley<sup>3</sup> noted that approximately 12% to 60% of applied force in fixed orthodontics is lost to resistance to sliding.

Force loss due to resistance to sliding makes orthodontic treatment unpredictable and requires greater forces than ideal in order to facilitate tooth movement. However, using greater forces increases the risk of undermining bone resorption and root resorption.<sup>4</sup> Thus, a thorough understanding of resistance to sliding may be extremely beneficial. Kusy and Whitley<sup>3</sup> divided resistance to sliding into three separate components: classical friction, elastic binding, and plastic binding or physical notching.

Classical friction occurs when the wire is passively resting in the bracket slot without any angulations and without touching the mesial or distal bracket slot edges. In this instance, the frictional force is equal to the normal force multiplied by the coefficient of friction which is a dimensionless value based on the properties of the two materials in contact.<sup>5</sup>

Classical friction can be further divided into two components: static and kinetic friction. Static friction is the force preventing the initial motion between two surfaces. Kinetic friction, which is usually less than static friction, then opposes the direction of motion of the object. Coulomb's third law of friction states that friction is independent of the relative velocity of the sliding motion. However, this law is generally disregarded at low velocities as there is no distinction between static and kinetic friction during orthodontic tooth movement at this force level.<sup>2</sup> Furthermore, tooth movement is considered to be intermittent rather than continuous movement and thus the effects of kinetic friction are minimized.<sup>3</sup>

Binding occurs when the bracket is tipped enough that the archwire comes into contact with the mesial and distal edges of the bracket. The angle at which this contact occurs is known as the critical angle.<sup>6</sup> The critical contact angle can be determined geometrically and is typically about  $2.0^\circ$  for a  $0.019 \times 0.025$ " archwire and a  $0.022 \times 0.028$ " bracket slot.<sup>7</sup> The contact between the bracket edges and the archwire creates an interference and thereby increases the resistance to sliding. As friction increases with the normal force, the binding force increases with the angulation of the bracket.<sup>8</sup>

Notching occurs when permanent deformation of the wire occurs at the wire-bracket corner interface. It may be defined as the mechanical damage occurred to the archwire at the latter stages of binding. It creates a sluggish movement and forms obstacles that have the potential to cease sliding altogether.<sup>9</sup>

As one would expect, the three components of resistance to sliding are not equally contributory to the total resistance. In an extensive review, Burrow<sup>10</sup> noted that binding makes up the vast majority of resistance to sliding. Articolo and Kusy<sup>8</sup> showed that when a  $0.021 \times 0.025$ " archwire with a  $3^\circ$  angulation slides through a  $0.022$ " bracket slot, binding makes up 73% of the resistance to sliding. When the angle is increased to  $7^\circ$ , binding produces 94% of

the resistance to sliding. Furthermore, recent studies showed that such angles of tip should be expected clinically. For example, during sliding mechanics a retracted canine tips an average of  $3.4^\circ$ .<sup>11</sup> In another study, it was reported that  $7.94^\circ$  of tipping occurred during canine retraction.<sup>12</sup>

In the literature, several approaches to reduce resistance to sliding have been taken including variations in wire dimensions, wire coatings, ligature coatings, variation in ligature materials, and by far the most popular, self-ligation.<sup>13-18</sup>

In recent years, significant attention has been placed on self-ligating brackets as a means of decreasing resistance to sliding.<sup>13</sup> Self-ligating brackets hold the wire into the slot, with a door that essentially converts the bracket slot into a tube, thereby negating the need for a steel or elastomeric ligature to hold the wire into the bracket slot. A self ligating bracket is considered passive when the bracket slot door exerts no force on a passively placed bracket. Alternatively, a self-ligating bracket is considered active when the bracket slot door exerts a positive force on a passively placed archwire, thereby forcing it into the slot. Thorstenson and Kusy<sup>19</sup> showed that when a 0.022" bracket is slid along a 0.019 x 0.025" archwire with no rotations, angulations or torque, that self-ligating brackets do indeed have lower frictional forces. Because the geometry and material properties of the self-ligating brackets and traditional brackets are nearly identical, these reduced frictional properties are primarily due to the absence of the frictional forces created by an elastomeric or steel ligature. However, when the same brackets were angled at physiological degrees of tip, there were no statistically significant differences between the amounts of resistance to sliding between the self-ligating and conventional bracket systems. This is expected because self-ligating brackets have no effect on binding, which as was noted previously, plays a much larger role than classical friction in its contribution to resistance to sliding.<sup>10</sup>

A novel approach to bracket design aimed at reducing not only the friction but also the binding and notching could have significant effects on reducing resistance to sliding. A bracket with reduced resistance to sliding could move teeth more predictably by effectively expressing the forces directly on the teeth involved.

The purpose of this study was to determine whether a novel bracket design could reduce the amount of resistance to sliding at varying degrees of tip when compared to conventional and self-ligating brackets. The null hypothesis was that there were no statistically significant differences in resistance to sliding between the novel, traditional and self-ligating brackets.

## Materials and Methods

Four types of brackets (n=5, each) were tested in this study: a conventional bracket, the Victory Series™ Low Profile bracket (3M Unitek, Monrovia, CA), a passive self-ligating bracket, the Damon Q bracket (Ormco Corp, Orange, CA), an active self-ligating bracket, the In-Ovation R bracket (Dentsply GAC, Bohemia, NY), and a novel twin bracket (Figure 1).

The novel twin bracket was manufactured by Micro Precision Parts Manufacturing Ltd. (Qualicum Beach, BC) via Computer Numerical Control (CNC) milling (technique). The novel bracket was similar to a traditional twin bracket but with Teflon (Dupont, Wilmington, DE) coated stainless steel pins (Amazon Supply, Seattle, WA) positioned precisely at the four corners of the bracket slot (Figure 2). The walls of the slot were recessed to prevent any contact with an inserted archwire and the rollers were positioned in such a way to maintain the integrity of the slot dimensions. The pins were hand inserted and individually observed under a microscope to ensure movement of the Teflon pins was not affected. The rationale behind this design was that the low coefficient of friction innate to the Teflon pins would alleviate the frictional forces between the bracket and the rolling of the pins with the potential of reducing the overall binding and notching (Figure 3).

All four bracket types had 0.022" slot widths and were made of stainless steel. The prescription differences of the brackets were non-consequential as all prescribed bracket angulations were compensated for during testing by the design of the custom-made jig. The jig was fabricated in a way that it could be clamped onto the mechanical testing machine (MTS

Insight 30 MTS, Eden Prairie, MN) and could be manipulated in 1° increments of second-order tipping at the bracket slot of an upper canine bracket (Figure 4).

The jig and the testing protocol were the same as the ones used in a previous study.<sup>20</sup> The jig was comprised of two parts. One part, which was firmly mounted to the jig baseplate, was designed to hold a straight wire with variable tension. The length of the test wire was set at 18.4mm to represent the clinical wire span present during a premolar extraction case and all wires were subjected to a 300g tensile force as previously recommended by Kapila et al.<sup>21</sup> The other half of the jig was designed to hold the bracket mounted to a stainless steel slug at varying degrees of tip. This half of the jig was able to hinge in such a manner as to allow the mounted bracket to be brought to the mounted wire and ligated together.

In the present study, a 0.021x0.025" calibration wire was inserted into the jig and tensed to 300g as measured by the MTS Insight 30. A bracket was then ligated to the wire and a blank mounting rod was inserted into the jig. The large sized wire was used to ensure correct alignment and the removal of all tip and torque. The jig was set to 0° of tip and Transbond XT (3M Unitek, Monrovia, CA) light cure adhesive paste was applied to the base of the bracket and the end of the mounting rod. The hinged rod was brought to the vertical position so that the composite on the mounting stub coalesced with the composite on the base of the bracket. The bracket was positioned to lie in the center of the mounting rod and the composite was then cured by light activation for 10 seconds on either side of the bracket. A total of twenty brackets were mounted in one session on the same 0.021x0.025" wire to avoid any variation between mountings.

Once the 0.019 x 0.025" archwire was placed into the jig, cinched into place and tensed to 300g, one of the previously calibrated brackets was then inserted and tightened into the

opposing part of the jig. The hinged rod was then brought into a parallel position with the wire so that the bracket and the wire could be ligated.

A loop of 0.032" round stainless steel wire, clamped to the upper member of the testing machine was positioned under the bracket tie wings (Figure 5). The testing machine was calibrated to zero to account for the weight of the clamp and wire loop prior to each test. With the bracket positioned at the bottom of the test wire, the loop was raised until it just touched the bracket so that a reading registered on the dial of the testing machine. Tip values were then applied by rotating the mounting jig and bracket. The bracket was then moved up by 3.7mm to represent the distance between the distal edge of an upper second premolar bracket and the mesial edge of a first molar tube. The initial force peak was recorded over a wire span of 3mm at a speed of 5mm/min (Figure 6). The initial force peak was recorded as the maximum force value within the first 0.5mm of bracket movement. After every 10 consecutive tests, the same experimental protocol was run but without the mounted 0.019 x 0.025" straight wire. This procedure was done to account for the inherent sliding resistance of the testing jig.

Each bracket was tested at 0°, 2°, 4°, 6°, and 8° of tip and a new 0.019 x 0.025" wire was replaced following each bracket to account for any wire bending or fatigue during the testing. The bracket testing order and the five different degrees of tip for each bracket were both randomized during the experiment.

The resistance to sliding was measured in newtons (N) for each experimental condition and the results were analyzed using one-way analysis of variance (ANOVA) using Microsoft Excel software (Microsoft Corp, Redmond, Wash). Post-hoc Student's T-test was performed following positive ANOVA tests to identify significance between groups. The level of significance for all the tests was set at  $P < 0.05$ .

## Results

When the jig was tested with a mounted bracket but no archwire, the system demonstrated an inherent resistance to sliding of 0.733N ( $\pm 0.029$ ) and this value was deducted from all measurements in order to isolate the actual resistance to sliding of the archwire/bracket/ligature system.

The summary of results showing the resistance to sliding for the four groups is shown in Table 1. When each of the bracket types was analyzed individually, the ANOVA confirmed that an increase in tip produces a significant change in the resistance to sliding ( $P < 0.001$ ). However, a cross-tabulation of the results showed no significant differences for any of the bracket types between  $0^\circ$  and  $2^\circ$  of tipping.

At  $0^\circ$  of tip, the average amount of resistance to sliding was 0.74N ( $\pm 0.10$ N) for the 3M bracket, 0.53N ( $\pm 0.11$ N) for the Novel Bracket, 0.29N ( $\pm 0.39$ N) for the Damon bracket and 0.70N ( $\pm 0.26$ N) for the In-Ovation bracket. One-way ANOVA analysis showed a significant difference between the different bracket types. Both the Damon bracket and the novel bracket had significantly less resistance to sliding than the 3M bracket, ( $P = 0.040$  and  $P = 0.013$ , respectively) (Table 1, Figure 7).

At  $2^\circ$  of tip, the average amount of resistance to sliding was 0.74N ( $\pm 0.11$ N) for the 3M bracket, 0.90N ( $\pm 0.45$ N) for the Novel Bracket, 0.53N ( $\pm 0.58$ N) for the Damon bracket and 0.70N ( $\pm 0.27$ N) for the In-Ovation bracket.



At 4° of tip, the average amount of resistance to sliding was 3.78N ( $\pm$  0.57N) for the 3M bracket, 5.00N ( $\pm$  0.69N) for the Novel Bracket, 4.82N ( $\pm$  1.24N) for the Damon bracket and 4.28N ( $\pm$  0.76N) for the In-Ovation bracket.

At 6° of tip, the average amount of resistance to sliding was 7.70N ( $\pm$  0.24N) for the 3M bracket, 8.91N ( $\pm$  0.58N) for the Novel Bracket, 8.94N ( $\pm$  1.96N) for the Damon bracket and 8.71N ( $\pm$  0.95N) for the In-Ovation bracket.

At 8° of tip, the average amount of resistance to sliding was 12.10N ( $\pm$  0.47N) for the 3M bracket, 13.42N ( $\pm$  0.92N) for the Novel Bracket, 12.99N ( $\pm$  1.98N) for the Damon bracket and 13.78N ( $\pm$  1.41N) for the In-Ovation bracket. ANOVA analysis showed that there were no statistical differences between any of the bracket types at 2, 4, 6 or 8° of tip (Figure 8-12).

Since during orthodontic tooth movement force levels are typically expressed in grams rather than newtons, the data are provided in Table 2 in grams. The average resistance to sliding at 0° for the Damon bracket was 29.99 grams while the force at 6° averaged 911.35 grams. In comparison, the 3M bracket had 75.61 grams of resistance at 0° and 785 grams at 6°.

## Discussion

Several studies have evaluated the resistance to sliding between self-ligating and traditionally ligated brackets.<sup>22-25</sup> These studies have consistently shown that when no angulations are introduced to the brackets, self-ligating brackets have significantly lower resistance to sliding. This study confirms those results in that the Damon self-ligating brackets had significantly lower resistance to sliding than the 3M conventionally ligated brackets when no tip was introduced. However, the novel bracket, which is a conventionally ligated bracket, also showed significantly lower resistance to sliding when compared to 3M's bracket.

The main differences between the novel bracket and 3M's traditional bracket can be divided into two categories: physical and mechanical properties. Both brackets were manufactured from low corrosion, high strength 300-series stainless steel. However, the pins inserted into the novel bracket were Teflon coated stainless steel. Teflon has a significantly lower coefficient of friction than stainless steel which accounts for the reduced friction rates found during orthodontic sliding tests with Teflon coated archwires and slots.<sup>15, 17, 26</sup> In the present study, these results were confirmed as reduced friction values were seen when no angulations were introduced. Although the frictional benefits were still present at the increased bracket angulations, the differences were masked by the increased binding forces.

The second alteration to the traditionally ligated bracket found in the novel bracket was the mechanical variation provided by the rolling pins. The purpose of the cylindrical pins in the novel bracket design was to improve the resistance to sliding by reducing binding that occurs during sliding. Binding is a result of elastic deformations in the archwire introduced by bracket

tipping that produce micromechanical obstructions that prevent bracket sliding and cause an increase in force loss. Theoretically, the ability of the cylindrical pins to rotate could allow the bracket to navigate the micromechanical deformations introduced by an angulated bracket.

The novel bracket design was expected to reduce the resistance to sliding at all degrees of tip. Unfortunately this was not observed in the present study. Microscopic inspection of the Teflon coated stainless steel rods indicated that the cut ends failed to maintain their cylindrical structure following the shearing process. Therefore, the imprecision in the rod structure might have contributed to the failure of the rods to rotate, negating the mechanical advantages of the novel bracket. More precise rod shape may prove to have an effect on bracket binding and provide the lower resistance to sliding as theoretically predicted. Further improvements to the cutting process of the rods may include abrasive waterjet cutting in order to preserve the cylindrical shape of the rods at the cut ends.

As mentioned previously, the critical angle for a 0.019 x 0.025" wire in a 0.022 x 0.028" bracket slot is approximately 2° depending on the bracket width.<sup>7</sup> Previous studies, have found increases in sliding resistance in association with the critical angle due to binding.<sup>7,8</sup> The current results are in agreement with previous assessments as this study showed that below the critical angle, between 0° and 2° of tipping, there were no differences in sliding resistance.

At high angles of tip, notching of the archwire may occur and cease movement. However, notching has been observed only at angulations above 9° and therefore was not observed in the present study as the highest tipping angle was only 8 degrees.<sup>9</sup>

Approximately 50% of applied force in orthodontic treatment is lost to resistance to sliding.<sup>2</sup> The present study validates the notion that bracket angulations increase the resistance and incidentally the force loss. Although bracket angulations as high as 8° are typically not present when significant sliding mechanics are applied on larger rectangular archwires,

angulations as high as 7° are common during canine retraction.<sup>12</sup> Nevertheless, our study showed that even at much smaller angulations, resistance to sliding still has a large impact on sliding mechanics.

There is considerable disagreement in the optimal force for tooth movement.<sup>27-29</sup> However, being able to understand accurately the force being applied toward tooth movement is clearly beneficial.<sup>8</sup> If an applied force is too low, tooth movement will not occur and if an orthodontist overestimates the necessary force then excessive pain, anchorage loss and other unwanted tooth movements may take place.<sup>3</sup>

Reducing the resistance to sliding of a bracket/wire/ligature system is one way to make the force being applied towards tooth movement more predictable. At 0° the Damon and the Novel bracket differed from the 3M bracket by 45.6 and 22.0 grams respectively which many would consider clinically relevant. Additionally, the resistances measured in this study at 4° and greater were more than the average initial force of a 6-unit powerchain stretched to twice its length.<sup>30</sup> A system with very low resistance to sliding would decrease the force loss and make the force necessary for orthodontic tooth movement more predictable, regardless of bracket angulation.

It should be noted that, in the present study, the Damon bracket showed a significantly greater variation between brackets than the other groups. This seems to confirm previous studies showing variations among brackets of the same type due to manufacturing imprecision.<sup>31,32</sup> Additionally, one of the Damon brackets specifically showed increased resistance to sliding at all degrees of tip. When the resistance to sliding values for that bracket were omitted from the results, the standard deviation values for the Damon bracket were normalized in comparison to the other bracket types but there were no changes in statistical significance results for any tests.

Although the present study aimed to simulate clinical applications, key differences were present. Tooth movement typically occurs at a rate of 1mm/mo, that is, an approximate average speed of  $2.3 \times 10^{-5}$ mm/min or  $3.9 \times 10^{-7}$ mm/s.<sup>33</sup> Yanase et al.<sup>2</sup> showed that frictional forces tend to increase as the sliding velocity decreases. However, testing speeds at such low velocity were not realistic in the present study due to the high number of tests required.

Additionally, the effect of salivary lubrication was not studied in the present in-vitro investigation since previous work has indicated that saliva exerts a negligible effect on friction. Clinically, the wet state may transition to a dry state as the contact between the bracket and archwire literally squeezes out the saliva.<sup>5</sup> Future studies with varying archwire dimensions and material should also be considered as sliding mechanics are consistently used on smaller archwire sizes and archwires made of materials other than stainless steel.<sup>34</sup>

The Teflon rod size in the present study was selected because it was large enough that it was available commercially yet small enough that it could be incorporated into a bracket of standard size. However, due to the inconsistencies in the shearing process, studies utilizing larger diameter Teflon rods are warranted. It should be noted that increases in rod diameter will necessitate a large bracket base in order to maintain the dimensions of the bracket slot.

The promising results from this initial study warrant further research, with larger sample sizes, into reduced resistance to sliding systems. Future studies involving the novel bracket may include variations in the rod cutting process and rod diameter in order to further reduce the resistance to sliding at varying bracket angulations. Additionally, significant sliding mechanics are also utilized on much smaller wires and future studies testing these brackets on varying wire sizes and dimensions may show varying results.

## Conclusion

1. The novel bracket showed a reduced resistance to sliding compared to the traditionally ligated, 3M bracket when no angulations were introduced to the bracket wire couple.
2. The Damon, self-ligating bracket showed a reduced resistance to sliding when compared to the 3M bracket at 0° of tip.
3. At 2, 4, 6, and 8° of tip, there were no significant differences between the different bracket types.
4. Second order angulations up to 2° have no effect on the resistance to sliding.
5. The resistance to sliding increases significantly as bracket tip increases.

Figures

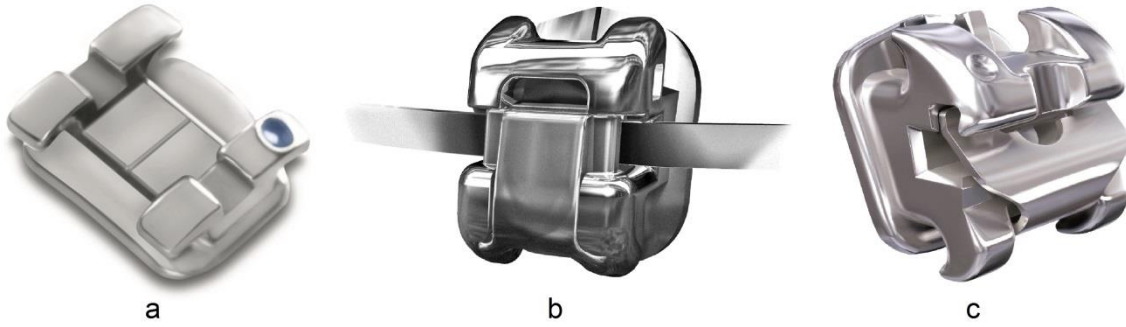


Figure 1: (a) Victory Series bracket, 3M Unitek; (b) Damon Q bracket, Ormco; (c) In-Ovation R bracket, GAC Dentsply

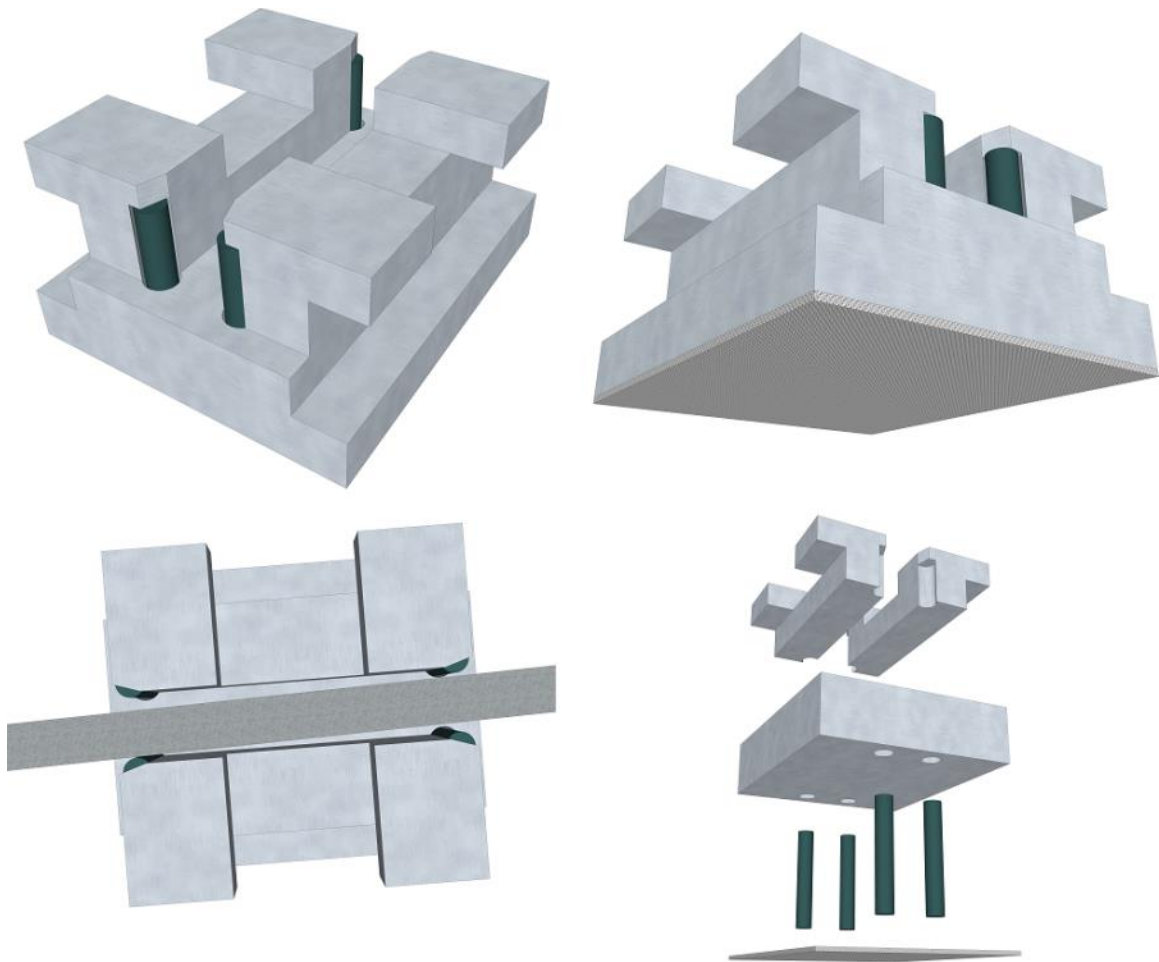


Figure 2: The novel bracket design including an exploded view (lower right)

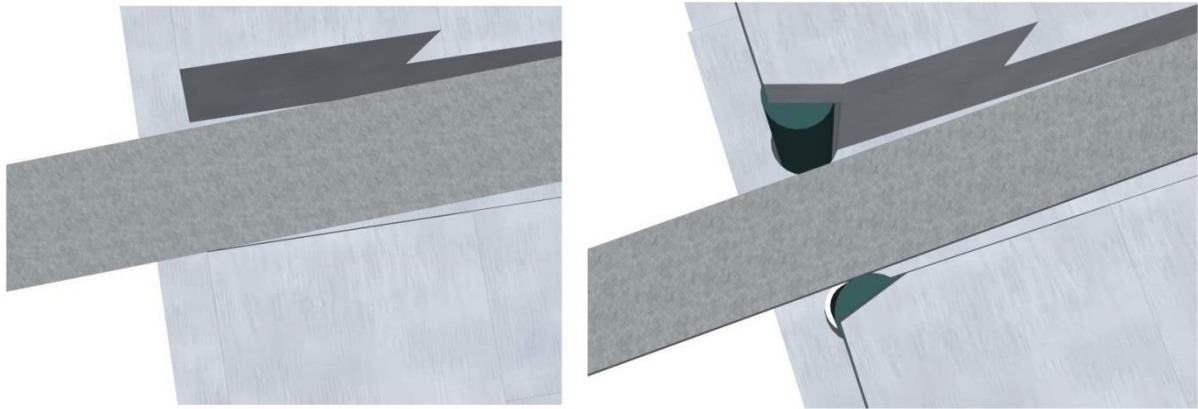


Figure 3: Magnified version of traditional bracket/wire contact and novel bracket/wire contact.



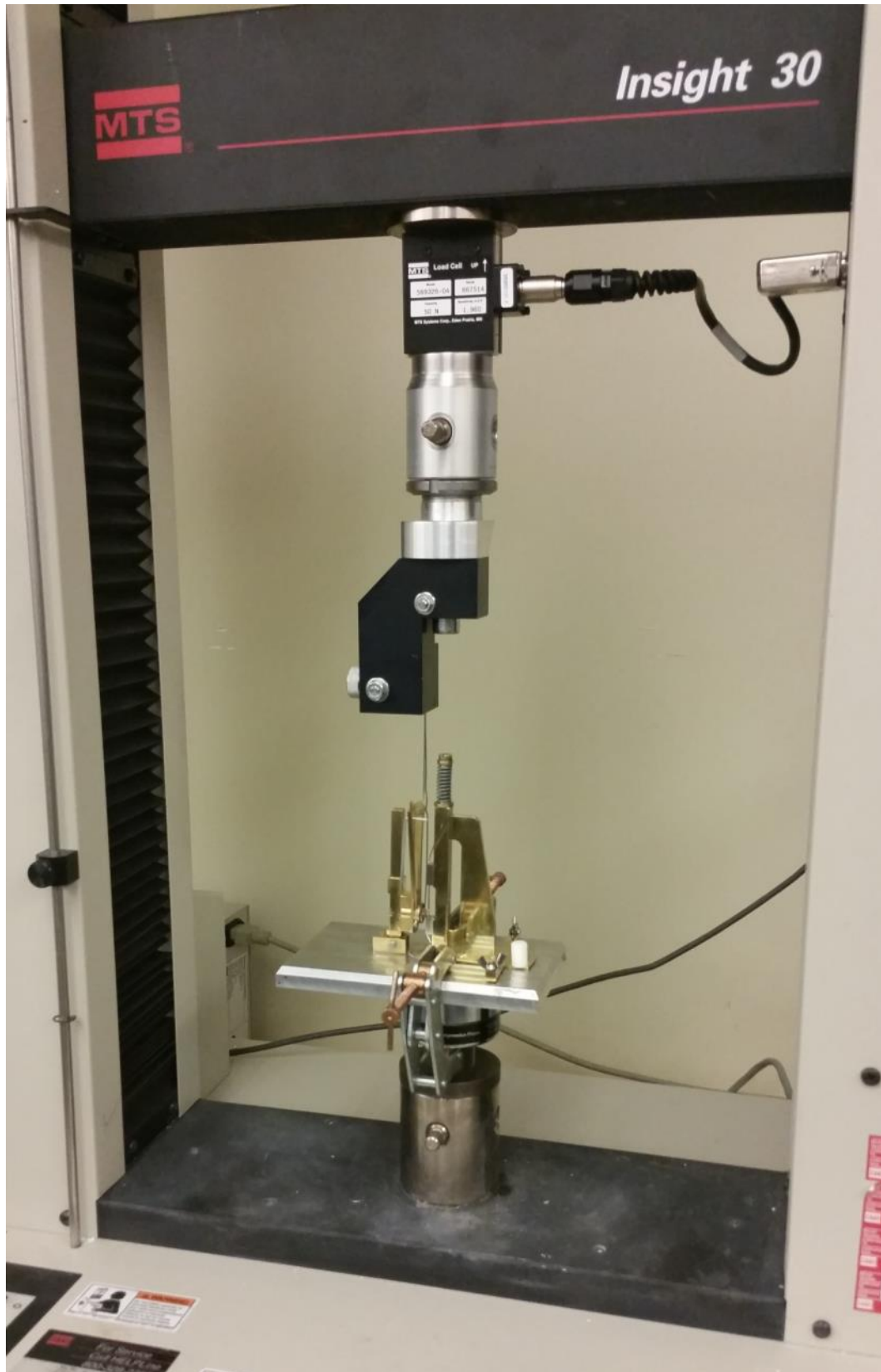


Figure 4: The testing jig mounted onto the MTS Insight 30 testing machine

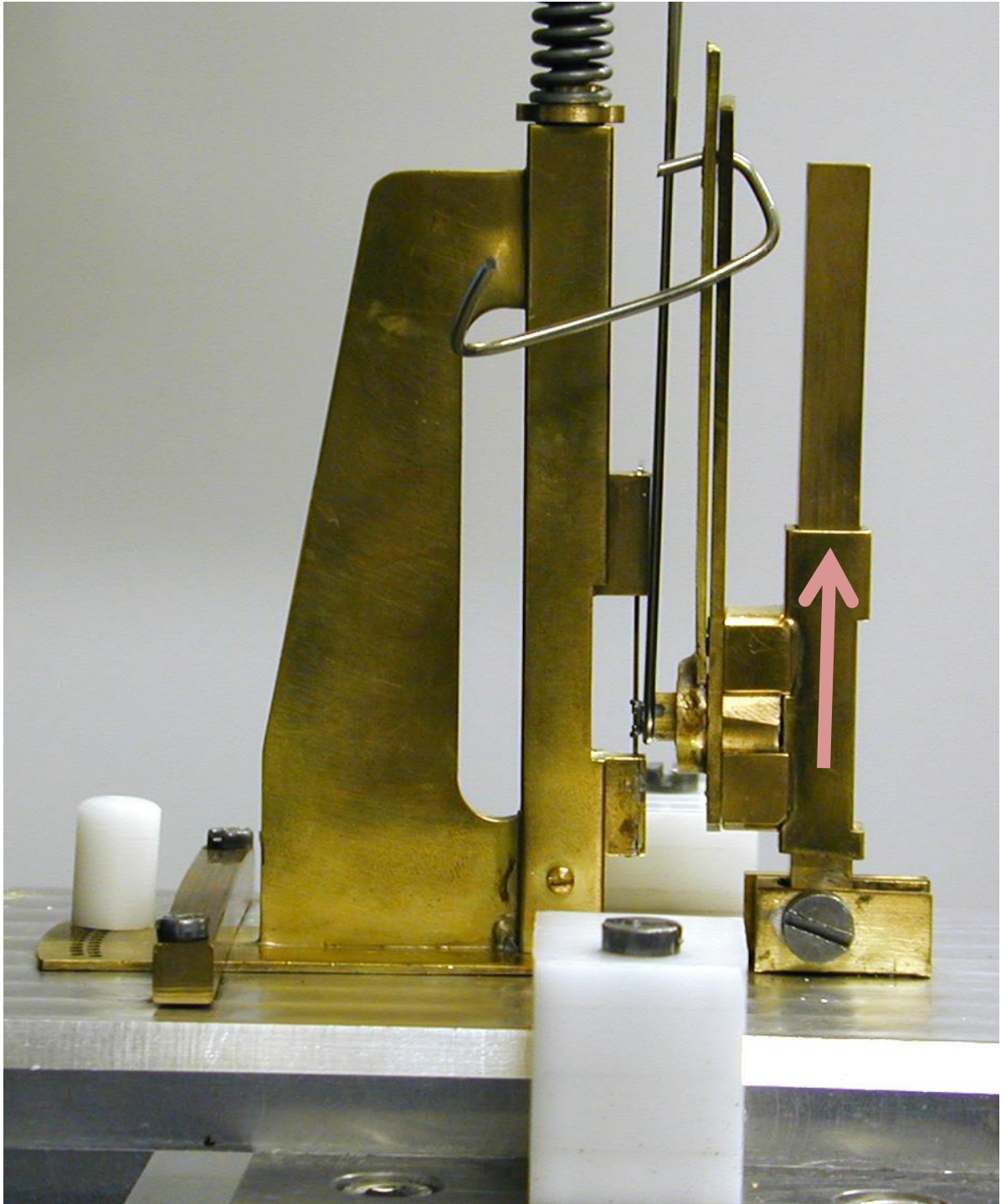


Figure 5: The testing jig with the wire loop placed below the bracket being tested

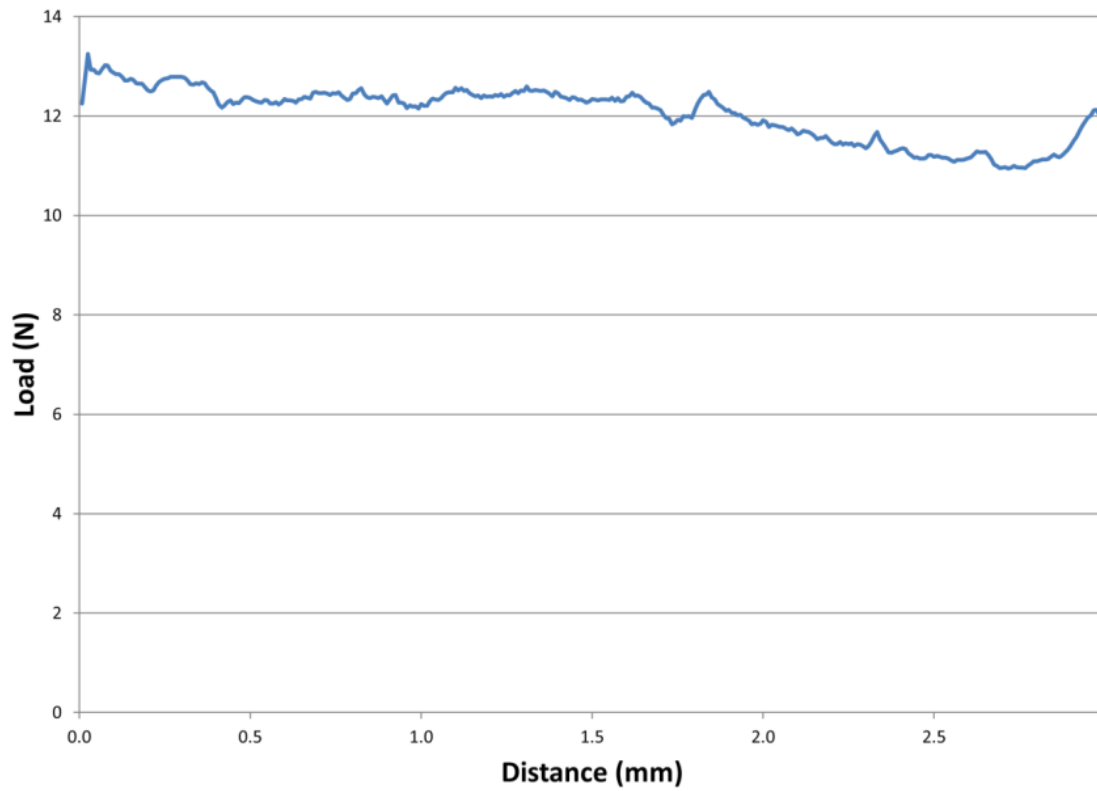


Figure 6: Sample data from the MTS Insight 30 testing machine

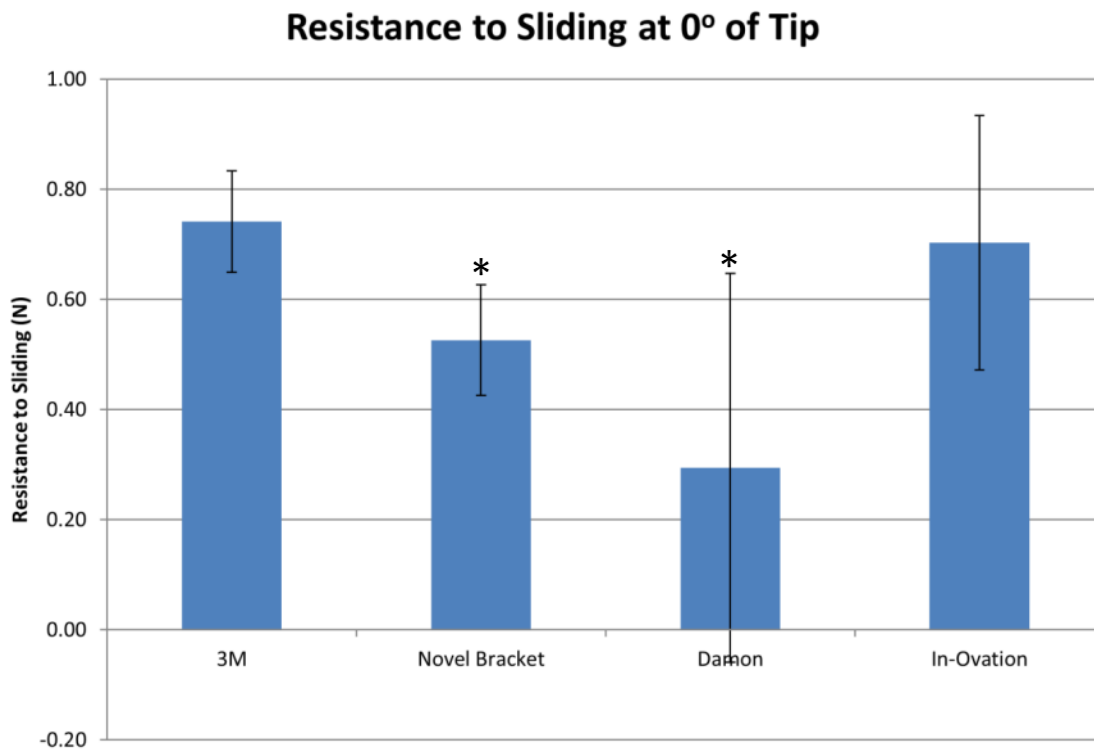


Figure 7: Average resistance to sliding for the tested brackets at 0° of tip

\*P < 0.05 when compared to 3M bracket

## 3M

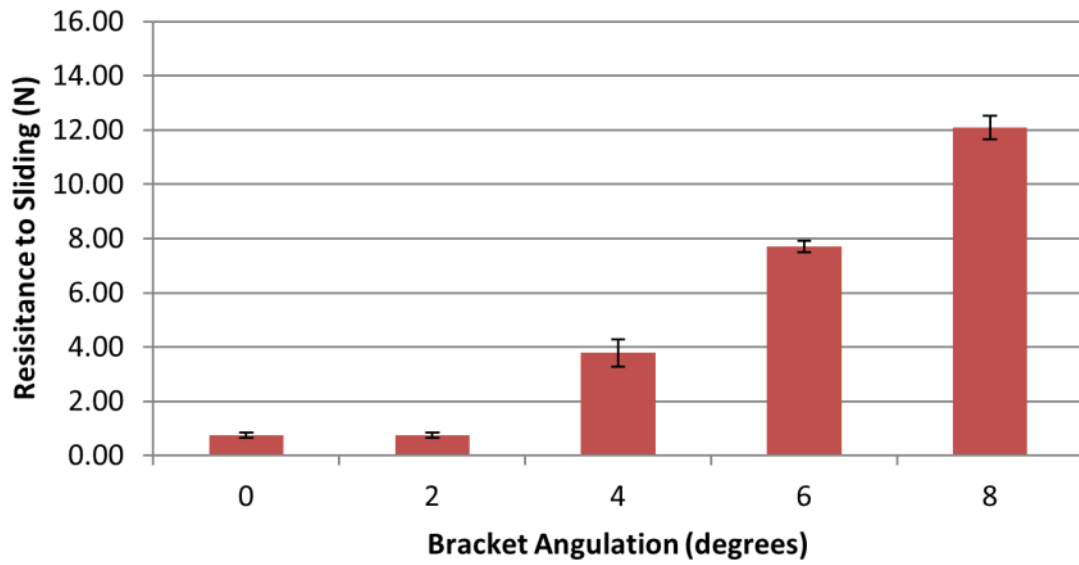


Figure 8: Average resistance to sliding for the 3M bracket at 0, 2, 4, 6, and 8° of tip

## Damon

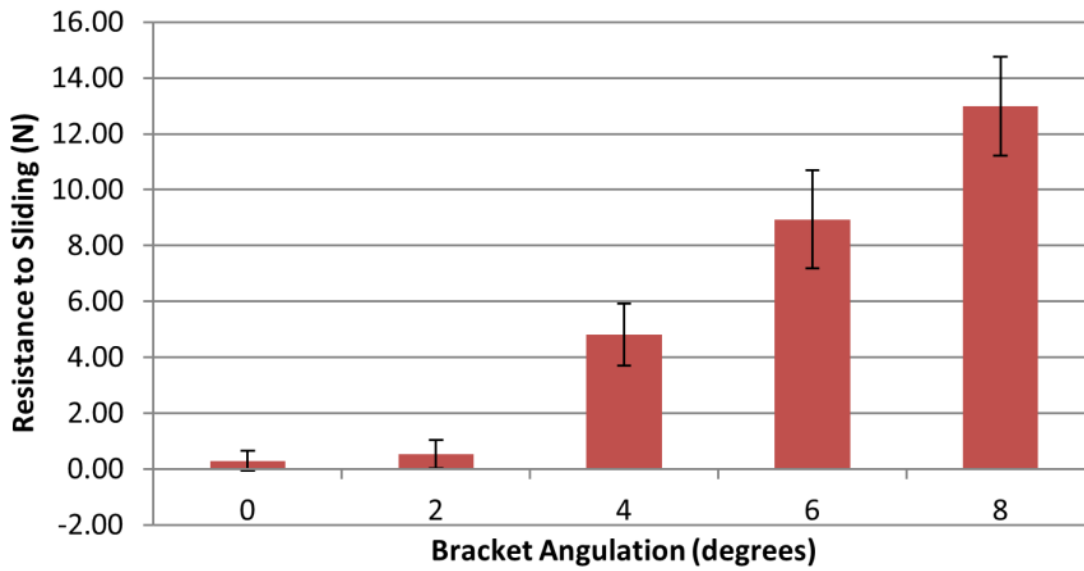


Figure 9: Average resistance to sliding for the Damon bracket at 0, 2, 4, 6, and 8° of tip

## In-Ovation

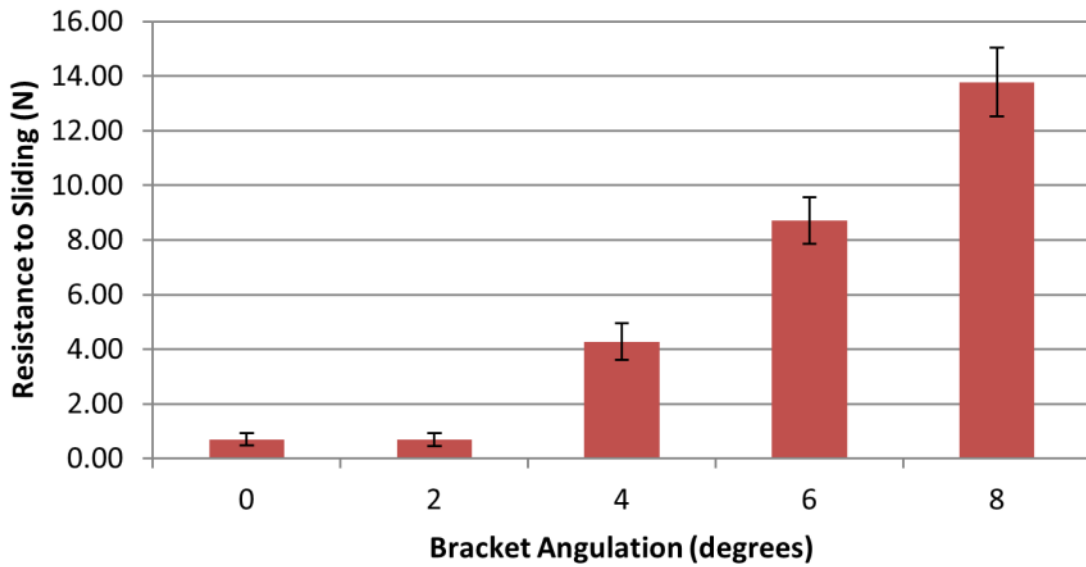


Figure 10: Average resistance to sliding for the In-Ovation bracket at 0, 2, 4, 6, and 8° of tip

## Novel Bracket

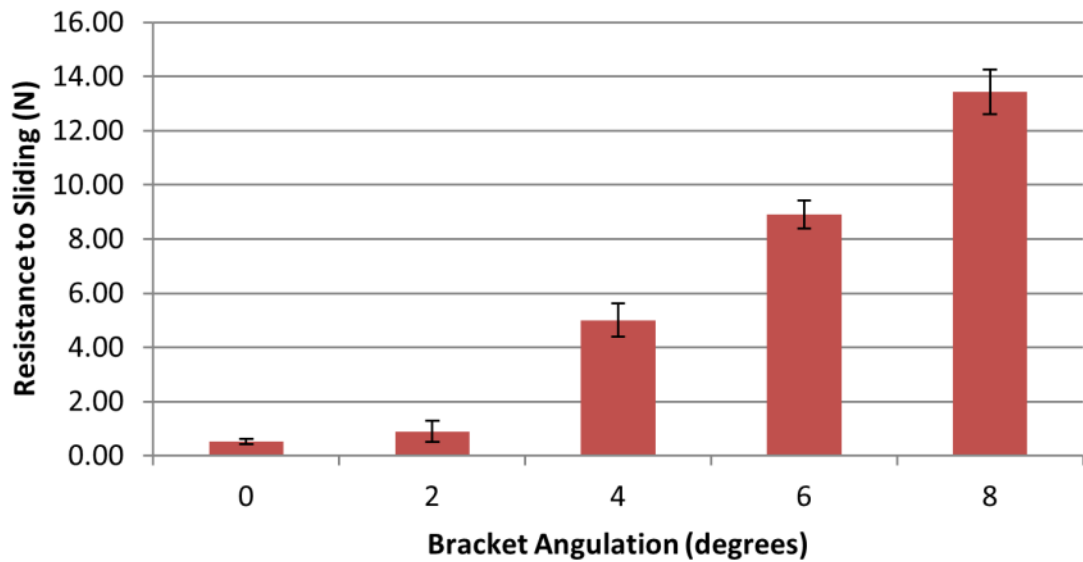


Figure 11: Average resistance to sliding for the Novel Bracket at 0, 2, 4, 6, and 8° of tip

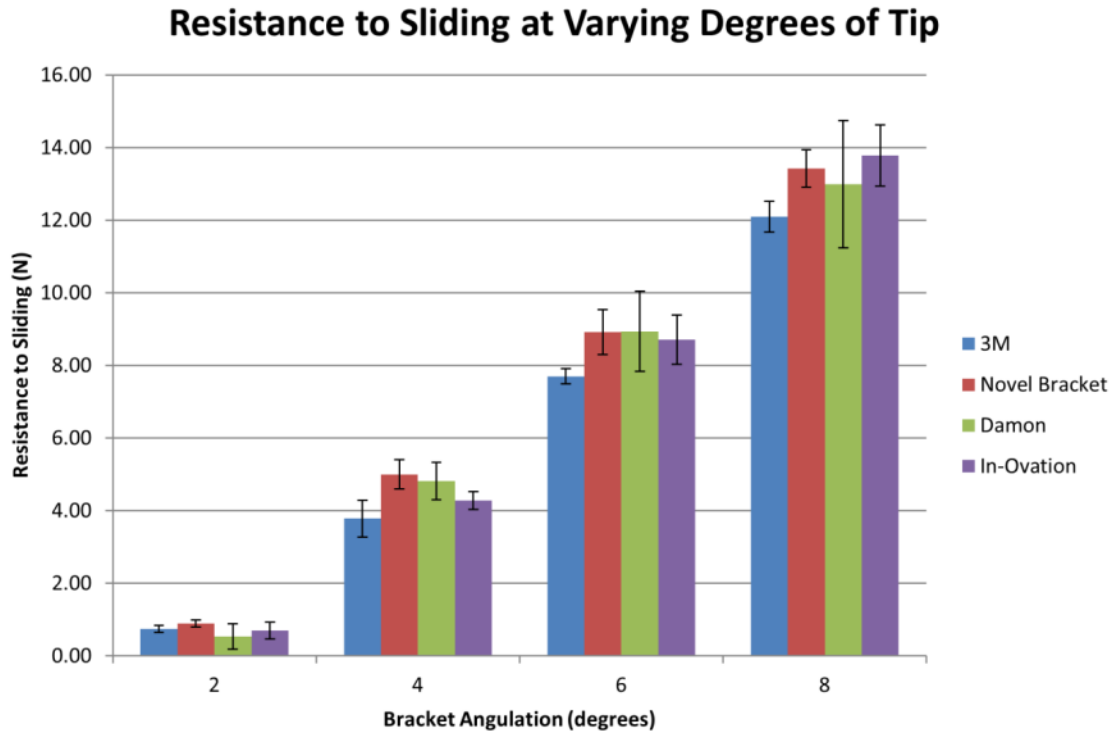


Figure 12: Average resistance to sliding for the tested brackets at 2, 4, 6, and 8° of tip.

## Tables

Table 1: Average resistance to sliding for 0, 2, 4, 6, and 8° of tip (newtons). \*P <0.05 when compared to 3M bracket

Bracket Type	0°		2°		4°		6°		8°		P-value
	(mean ± SD, N)	(mean ± SD, N)	(mean ± SD, N)	(mean ± SD, N)	(mean ± SD, N)	(mean ± SD, N)	(mean ± SD, N)	(mean ± SD, N)	(mean ± SD, N)	(mean ± SD, N)	
3M	0.74	0.10	0.74	0.11	3.78	0.57	7.70	0.24	12.10	0.47	<.001
Novel Bracket	*0.53	0.11	0.90	0.45	5.00	0.69	8.91	0.58	13.42	0.92	<.001
Damon	*0.29	0.39	0.53	0.58	4.82	1.24	8.94	1.96	12.99	1.98	<.001
In-Ovation	0.70	0.26	0.70	0.27	4.28	0.76	8.71	0.95	13.78	1.41	<.001
Group P-value	0.04		0.56		0.14		0.30		0.25		

Table 2: Average resistance to sliding for 0, 2, 4, 6, and 8° of tip (grams)

Bracket Type	0° (grams)	2° (grams)	4° (grams)	6° (grams)	8° (grams)
3M	75.61	75.78	385.75	785.40	1233.54
Novel Bracket	53.63	91.32	509.97	909.07	1368.82
Damon	29.99	54.42	491.11	911.35	1324.70
In-Ovation	71.66	70.92	436.10	888.26	1405.15

## References



## References

1. Montasser MA, El-Bialy T, Keilig L, Reimann S, Jager A, Bourauel C. Force loss in archwire-guided tooth movement of conventional and self-ligating brackets. *Eur J Orthod.* 2014;36:31-38.
2. Yanase Y, Ioi H, Nishioka M, Takahashi I. Effects of sliding velocity on friction: An in vitro study at extremely low sliding velocity approximating orthodontic tooth movement. *Angle Orthod.* 2013;84:451-458.
3. Kusy RP, Whitley JQ. Friction between different wire-bracket configurations and materials. Elsevier; 1997;3:166-177.
4. Matarese G, Nucera R, Militi A, Mazza M, Portelli M, Festa F, Cordasco G. Evaluation of frictional forces during dental alignment: an experimental model with 3 nonleveled brackets. *Am J Orthod Dentofac Orthop.* 2008;133:708-715.
5. Kusy RP, Whitley JQ, Prewitt MJ. Comparison of the frictional coefficients for selected archwire-bracket slot combinations in the dry and wet states. *Angle Orthod.* 1991;61:293-302.
6. Kusy RP, Whitley JQ. Influence of archwire and bracket dimensions on sliding mechanics: derivations and determinations of the critical contact angles for binding. *Eur J Orthod.* 1999;21:199-208.
7. Thorstenson GA, Kusy RP. Effect of archwire size and material on the resistance to sliding of self-ligating brackets with second-order angulation in the dry state. *Am J Orthod Dentofac Orthop.* 2002;122:295-305.
8. Articulo LC, Kusy RP. Influence of angulation on the resistance to sliding in fixed appliances. *Am J Orthod Dentofac Orthop.* 1999;115:39-51.
9. Articulo LC, Kusy K, Saunders CR, Kusy RP. Influence of ceramic and stainless steel brackets on the notching of archwires during clinical treatment. *Eur J Orthod.* 2000;22:409-425.
10. Burrow SJ. Friction and resistance to sliding in orthodontics: a critical review. *Am J Orthod Dentofac Orthop.* 2009;135:442-447.
11. Kojima Y, Fukui H. Numerical simulation of canine retraction by sliding mechanics. *Am J Orthod Dentofac Orthop.* 2005;127:542-551.
12. Hayashi K, Uechi J, Murata M, Mizoguchi I. Comparison of maxillary canine retraction with sliding mechanics and a retraction spring: a three-dimensional analysis based on a midpalatal orthodontic implant. *Eur J Orthod.* 2004;26:585-589.

13. Rinchuse DJ, Miles PG. Self-ligating brackets: present and future. *Am J Orthod Dentofac Orthop.* 2007;132:216-222.
14. Hain M, Dhopatkar A, Rock P. The effect of ligation method on friction in sliding mechanics. *Am J Orthod Dentofac Orthop.* 2003;123:416-422.
15. De Franco DJ, Spiller Jr RE, Von Fraunhofer J. Frictional resistances using Teflon-coated ligatures with various bracket-archwire combinations. *Angle Orthod.* 1995;65:63-72.
16. Farronato G, Casiraghi G, Gianni A, Salvato A. The use of PTFE in orthodontics. *Mondo Ortod.* 1988;13:83-89.
17. Farronato G, Maijer R, Carìa MP, Esposito L, Alberzoni D, Cacciatore G. The effect of Teflon coating on the resistance to sliding of orthodontic archwires. *Eur J Orthod.* 2012;34:410-417.
18. Cantarella D, Lombardo L, Siciliani G. The dynforce archwire. *Ann Stomatol.* 2013;4:204.
19. Thorstenson GA, Kusy RP. Comparison of resistance to sliding between different self-ligating brackets with second-order angulation in the dry and saliva states. *Am J Orthod Dentofac Orthop.* 2002;121:472-482.
20. Hamdan A, Rock P. The effect of different combinations of tip and torque on archwire/bracket friction. *Eur J Orthod.* 2008;30:508-514.
21. Kapila S, Angolkar PV, Duncanson Jr MG, Nanda RS. Evaluation of friction between edgewise stainless steel brackets and orthodontic wires of four alloys. *Am J Orthod Dentofac Orthop.* 1990;98:117-126.
22. Lee C, Hwang SM. A comparative study of frictional force in self-ligating brackets according to the bracket-archwire angulation, bracket material, and wire type. *The Korean J Orthod.* 2015;45:13-19.
23. Thomas S, Sherriff M, Birnie D. A comparative in vitro study of the frictional characteristics of two types of self-ligating brackets and two types of pre-adjusted edgewise brackets tied with elastomeric ligatures. *Eur J Orthod.* 1998;20:589-596.
24. Krishnan M, Kalathil S, Abraham KM. Comparative evaluation of frictional forces in active and passive self-ligating brackets with various archwire alloys. *Am J Orthod Dentofac Orthop.* 2009;136:675-682.
25. Stefanos S, Secchi AG, Coby G, Tanna N, Mante FK. Friction between various self-ligating brackets and archwire couples during sliding mechanics. *Am J Orthod Dentofac Orthop.* 2010;138:463-467.
26. Redlich M, Katz A, Rapoport L, Wagner H, Feldman Y, Tenne R. Improved orthodontic stainless steel wires coated with inorganic fullerene-like nanoparticles of WS<sub>2</sub> impregnated in electroless nickel-phosphorous film. *Dent Mater.* 2008;24:1640-1646.

27. Storey E, Smith R. Force in orthodontics and its relation to tooth movement. *Aust J Dent.* 1952;56:11-18.
28. Quinn RS, Yoshikawa DK. A reassessment of force magnitude in orthodontics. *Am J Orthod.* 1985;88:252-260.
29. Andreasen G, Johnson P. Experimental findings on tooth movements under two conditions of applied force. *Angle Orthod.* 1967;37:9-12.
30. Kim K, Chung C, Choy K, Lee J, Vanarsdall RL. Effects of prestretching on force degradation of synthetic elastomeric chains. *Am J Orthod Dentofac Orthop.* 2005;128:477-482.
31. Cash A, Good S, Curtis R, McDonald F. An evaluation of slot size in orthodontic brackets-are standards as expected? *Angle Orthod.* 2004;74:450-453.
32. Joch A, Pichelmayer M, Weiland F. Bracket slot and archwire dimensions: manufacturing precision and third order clearance. *J Orthod.* 2010;37:241-249.
33. Kusy R, Whitley J. Effects of sliding velocity on the coefficients of friction in a model orthodontic system. *Dent Mater.* 1989;5:235-240.
34. Cacciafesta V, Sfondrini MF, Ricciardi A, Scribante A, Klersy C, Auricchio F. Evaluation of friction of stainless steel and esthetic self-ligating brackets in various bracket-archwire combinations. *Am J Orthod Dentofac Orthop.* 2003;124:395-402.

## Vita

Dr. James Newell Blackburn was born on June 11, 1986 in Framingham, Massachusetts. After graduating Glendora High School in 2004, he spent two years in Malaysia where he became fluent in Bahasa Melayu. He returned to study biology at Brigham Young University, where he graduated with honors in 2009. He then matriculated to UCLA School of Dentistry as a Regents Scholar and graduated in 2013 with honors. James subsequently gained admission to the graduate orthodontic program at Virginia Commonwealth University Department of Orthodontics and received a Certificate in Orthodontics as well as a Master of Science in Dentistry degree in 2015. After graduation, Dr. James Blackburn will enter the private practice of orthodontics.