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# Evaluation of frictional forces between brackets of different types at various angulations and an arch wire: With and without pulsating vibration

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EVALUATION OF FRICTIONAL FORCES BETWEEN BRACKETS OF  
DIFFERENT TYPES AT VARIOUS ANGULATIONS AND AN ARCH WIRE:  
WITH AND WITHOUT PULSATING VIBRATION

BENJAMIN M. CHRISTMAN, D.M.D.

A Thesis Presented to the Faculty of the College of Dental Medicine of  
Nova Southeastern University in Partial Fulfillment of the Requirements for the

Degree of  
MASTER OF SCIENCE

December 2015

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EVALUATION OF FRICTIONAL FORCES BETWEEN BRACKETS OF  
DIFFERENT TYPES AT VARIOUS ANGULATIONS AND AN ARCH WIRE:  
WITH AND WITHOUT MECHANICAL VIBRATION

By

BENJAMIN M. CHRISTMAN, D.M.D.

A Thesis Submitted to the College of Dental Medicine of Nova Southeastern  
University in Partial Fulfillment of the Requirements for the Degree of  
MASTER OF SCIENCE

Department of Orthodontics and Dentofacial Orthopedics

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Evaluation of Frictional Forces Between Brackets of different types at various angulations and an arch wire: with and without pulsating vibration

**DATE SUBMITTED:** December 7, 2015

**I certify that I am the sole author of this thesis, and that any assistance I received in its preparation has been fully acknowledged and disclosed in the thesis. I have cited any sources from which I used ideas, data, or words, and labeled as quotations any directly quoted phrases or passages, as well as providing proper documentation and citations. This thesis was prepared by me, specifically for the M.Sc. degree and for this assignment.**

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## **DEDICATION**

To all of my mentors, teachers, and friends who have inspired me along the way, especially those there from the beginning: my loving father and mother, Michael and Cyndi, and Ashley, my sister.

## **Acknowledgement**

---

I would like to acknowledge the following individuals:

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## Abstract

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### EVALUATION OF FRICTIONAL FORCES BETWEEN BRACKETS OF DIFFERENT TYPES AT VARIOUS ANGULATIONS AND AN ARCH WIRE: WITH AND WITHOUT PULSATING VIBRATION

DEGREE DATE: DECEMBER 10, 2015

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**Objective:** The objective of this study was to determine the effect of pulsating vibration on the sliding resistance between orthodontic brackets and stainless steel wires. Brackets were placed at two different angulations ( $0^\circ$  and  $5^\circ$ ) to simulate leveling of a tipped tooth during tooth movement. Pulsating vibration was delivered via the AcceleDent device.

**Background:** Friction is defined as a force that retards or resists the relative motion of two objects in contact, and its direction is tangential to the common boundary of the two surfaces in contact.<sup>1</sup> This has been of interest to the orthodontist since the mid-20<sup>th</sup> century. Since the time of Stoner's paper in 1960, the orthodontic literature has been full of studies done on friction in orthodontics including: friction with different ligation methods, friction among different arch wire materials, friction and different bracket materials, and friction with various



slot designs.<sup>2-14</sup> Understanding friction has led to the emergence of new technologies in orthodontics. One of the most popular is the self-ligating bracket. This popularity arose from claims that they reduce friction during treatment.<sup>15</sup> Other innovations have been introduced in the field of orthodontics to help accelerate tooth movement. Among these innovations is the application of a pulsating vibration during active orthodontic treatment. Such pulsating vibration can be delivered during orthodontic treatment by AcceleDent, which is a hands-free device designed by OrthoAccel Technologies, Inc., Bellaire, TX. The company claims the output force helps accelerate bone turnover. The following study investigated whether it could decrease treatment time via a different mechanism: decreasing frictional resistance to tooth movement along the arch wire.

**Methods:** A paper template was made of a typodont tooth with a bracket window cut out. The bracket cut out was made with the bracket window angulated 0° and 5°. 0.022" x 0.028" standard prescription edgewise brackets (American Orthodontics, Sheboygan, WI) of ceramic, twin and self-ligating design were bonded to 3 maxillary 1<sup>st</sup> premolar typodont teeth using the template. The teeth were leveled with a 0.019" x 0.025" SS arch wire and placed in a metal scaffold. They were held in place with Aquasil Ultra XLV wash material PVS (DENTSPLY Caulk, Milford, DE.). Only the middle bracket was adjusted for angulation and accuracy was checked with the iPhone 6 level. The AcceleDent Aura device (OrthoAccel Technologies, Inc., Bellaire, TX). was attached to the occlusal surface of the teeth via cable ties. The AcceleDent Aura device provided 30 Hz of

pulsating vibration. All tests were performed with a 0.019" x 0.025" SS arch wire pulled through the brackets via a Universal Testing Machine (Instron, Grove City, PA) at a crosshead speed of 2.5mm/min for 30 seconds. Frictional resistance was measured by averaging 6 recordings every 5 seconds. **Results:** The pulsating vibration provided by the AcceleDent device significantly reduced the resistance to sliding for each bracket type at both 0° and 5° ( $p < 0.05$ ). Ceramic brackets had the highest resistance to sliding of all bracket types. **Conclusions:** Pulsating vibration via the AcceleDent Aura device reduces the resistance to sliding between a bracket and arch wire *in vitro*. This may potentially decrease overall treatment time but more *in vivo* studies need to be done to evaluate this.

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## **Chapter 1: Introduction**

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### **1.1. Biological Mechanism of Tooth Movement**

There are two theories regarding the mechanism of tooth movement; and both may actually play a role. They are the biological electricity and pressure-tension theories. The pressure-tension theory is the classical theory of tooth movement.<sup>16</sup>

In order to move teeth orthodontically, pressure is applied to the teeth, which elicits a response by the periodontal ligament. The pressure is usually applied to the tooth by an arch wire via a bracket. After a few seconds of force application, fluid of the PDL is pushed out causing the tooth to shift in its socket. The PDL is compressed in the direction of force application and undergoes tension on the opposite side. The PDL can only withstand forces for a short duration before physiologic events initiate alveolar bone remodeling.<sup>16</sup>

Reitan studied histologic slides of teeth with continuous force applied to them and referred to 3 stages of tooth movement. After the first stage of PDL compression, an initial cell-free zone is created due to the complete occlusion of blood vessels in the PDL. This produces areas of necrosis and begins the hyalinization period. Before tooth movement continues, the hyalinized area must be removed by osteoclasts arriving from the backside of the bone. This is called “undermining resorption”. This can take up to four weeks and will slow down tooth movement.<sup>17</sup> Storey describes undermining resorption as the “interruption of nutrition, ischemia, and cell death, as well as inflammation and rupture of connective tissues...followed by the classic process of tissue repair.”<sup>18</sup> Once the

hyalinized areas are removed, the secondary phase begins and bone is removed in the direction of tooth movement via “frontal resorption”. The opposite occurs on the tension side; widening of the PDL space and an increase in cell proliferation and osteoblastic activity.<sup>19</sup>

Reitan also suggested that light forces should be used when moving teeth orthodontically to minimize hyalinization and undermining resorption.<sup>17</sup> Optimal force has been mentioned in the literature since the early 1900’s. Schwarz, in 1932, believed that there was an optimal force that elicited tooth movement; in which anything under would not move teeth and anything above would cause tissue damage or necrosis. Correct in this sense, he was wrong in his hypothesis that optimal pressure was equal to the pressure of blood in the capillaries in order to prevent necrosis.<sup>20</sup> Oppenheim and Reitan also mentioned the use of light forces was ideal for moving teeth.<sup>21, 22</sup> Unfortunately, not much ground on the ideal level of force has been made due to the difficulty in measuring stresses and strains at the periodontal level, inability to control the type of tooth movement, tooth movement occurring in more than one phase, and biologic individual variation.<sup>23</sup>

The biological electricity theory of tooth movement was derived from the piezoelectric phenomenon, which is seen in crystalline structures. As a force is applied, there is a slight bending of the crystal lattice and this produces an electrical current. As the force is released the current flows back in the opposite direction as the crystal lattice returns to its original shape.<sup>16</sup>



Basset and Becker, in 1962, discovered that when bone is subjected to loads, electric potentials are generated on its surface.<sup>24</sup> Then, Epker and Frost examined the stresses and strains caused by tooth movement, in order to find out how these potentials were generated.<sup>25</sup> In addition, they were puzzled by the fact that long bones often undergo bone apposition when compressed unlike alveolar bone. They discovered that when teeth are shifted in their sockets the PDL is compressed and the bone becomes less concave. This actually creates tension in the vertical direction along the long axis of the tooth. The PDL on the tension side creates bone that is more concave causing compression in the vertical direction. This bending of the bone, and not the compression or tension of the PDL, is what causes apposition or resorption.<sup>25</sup>

Zengo *et al*<sup>26</sup> was able to link the findings of these two previously mentioned studies with their work on beagle dogs, demonstrating that the electronegative side of alveolar bone was concave and appeared on the side coincident with bone apposition. The electropositive potential corresponded with the side undergoing resorption. More recently, it has been suggested that electric potentials caused by bone bending via orthodontic force and mechanical perturbation may increase the cellular response of the PDL, perhaps increasing the speed of orthodontic tooth movement.<sup>27</sup>

## **1.2. Friction in Orthodontics**

Friction is the force that resists the sliding of one solid object over another. This has been of interest to the orthodontist since the mid-20<sup>th</sup> century. Stoner mentioned in 1960, “recognition must always be given the fact that, because of

appliance inefficiency, sometimes applied force is dissipated by friction or improper application and it is difficult both to control and to determine the amount of force that is being received by the individual tooth”.<sup>28</sup> There are two types of friction: static and kinetic. In orthodontics, static friction needs to be overcome to initiate movement of the tooth along the arch wire. Once the bracket begins moving it encounters kinetic friction along the wire on which it is sliding.<sup>4, 21</sup>

Kinetic friction is encountered throughout orthodontic treatment, especially during initial leveling and aligning and space closure stages of treatment. As soon as the wire is ligated to the brackets the force of the wire is transferred to the tooth. This force compresses the periodontal ligament in the direction of the pressure, the blood supply is diminished, chemical messengers are released to recruit osteoclasts, and the alveolar bone is removed. This ultimately leads to tooth movement. When the teeth start to move, kinetic friction is encountered and the teeth start to tip. As the teeth tip and the bracket becomes angulated, the corners of the bracket have a tendency to bind against the arch wire.<sup>29</sup> “Binding” momentarily halts tooth movement. Overcoming binding is synonymous with overcoming static friction.<sup>15</sup> This process of tipping and binding is known as the “stick-slip phenomenon”.<sup>30</sup>

### **1.3. Material Science to Decrease Friction**

Since the time of Stoner’s paper, the orthodontic literature has been full of studies done on friction in orthodontics including: friction of arch wires with different ligation methods, friction amongst different arch wire materials, friction with different bracket materials, and friction with various slot designs.<sup>3-5, 8-10, 31</sup>

Understanding friction has led to the emergence of many, new technologies in orthodontics. One of the most prevalent being the development of self-ligating brackets.

#### **1.4. Pulsating Vibration to Accelerate Tooth Movement**

Other advancements have been made in the field of orthodontics to help accelerate tooth movement. One such innovation is the introduction of AcceleDent (OrthoAccel Technologies, Inc., Bellaire, TX), which is a hands-free device designed to apply 30 Hz of pulsating vibration to the dentition during orthodontic tooth movement.

The innovation of AcceleDent was derived from research on the effect of cyclic loading on craniofacial sutural growth. *In vivo* studies on rabbits and rats have shown that cyclic loading of no more than 20 minutes/day increased sutural width, sutural osteoblastic zones, and sutural osteoclastic zones.<sup>32-34</sup> After these studies were done on craniofacial sutures, *Nishimura et al.*<sup>35</sup> studied the effect of pulsating vibration with an average of 61 Hz on the activation of cellular messengers in the periodontal ligament tissues of rats. They showed that vibration has a statistically significant effect on tooth movement, as well as on the activation of the receptor activator of NF kappa B ligand (RANKL) expression. RANKL is known to be a key factor in the differentiation of osteoblastic cells to osteoclasts that initiate bone resorption.<sup>36</sup>

A clinical trial reported by AcceleDent claimed to complete initial aligning and leveling 2.06 times faster than without it, and a space closure increase of 1.38 times. The company states that the output force helps accelerate bone

turnover.<sup>37</sup> However, the evidence is weak and the majority of the reports are retrospective studies or case reports.<sup>38</sup> One recent study actually showed cyclic vibration to inhibit tooth movement in rats and a randomized clinical controlled trial by *Woodhouse et al.*<sup>30</sup> did not reveal a significant difference in the timing of tooth alignment with and without the use of AcceleDent.<sup>39</sup>

### **1.5. Importance of Study**

After Stoner recognized friction as an obstacle to efficient tooth movement in 1960, most of the technological advances to overcome friction have been based on material science, i.e. brackets, arch wires, and ligatures<sup>3, 5, 8-10, 28, 31</sup> Recent studies have examined whether vibration reduces friction. *Kusy* makes mention of vibration due to occlusal and chewing forces in his 2002 editorial in the American Journal of Orthodontics and Dentofacial Orthopedics, but ultimately writes it off as having a net neutral effect on tooth movement<sup>40</sup>. The most recent study involving vibration and resistance to sliding (Rs) displayed that vibrations did reduce it<sup>41</sup>. The study used a lab-fabricated device that is not readily available, to apply the pulsating vibration. This study differed in the fact that it tested a device that is readily available on the orthodontic market. In addition, AcceleDent produces a different amplitude and frequency of vibration compared to the one tested in the study above and it is useful to know if this has a similar effect on the Resistance to sliding.

## **1.6. Purpose, Specific Aims and Hypotheses**

### **1.6.1. Purpose**

The purpose of this study was to determine whether or not pulsating vibration reduces the resistance to sliding between orthodontic brackets (conventional, self-ligating, and ceramic) and a SS arch wire, and to determine if the bracket material affects the resistance to sliding.

### **1.6.2. Specific Aims**

1. To measure the resistance to sliding between brackets and wires, with and without pulsating vibration, at different angulations.
2. To measure and compare the resistance to sliding of various bracket materials, with and without vibration, to determine if the type of bracket has an effect on frictional resistance.

### **1.6.3. Hypotheses**

**H<sub>0</sub>:**

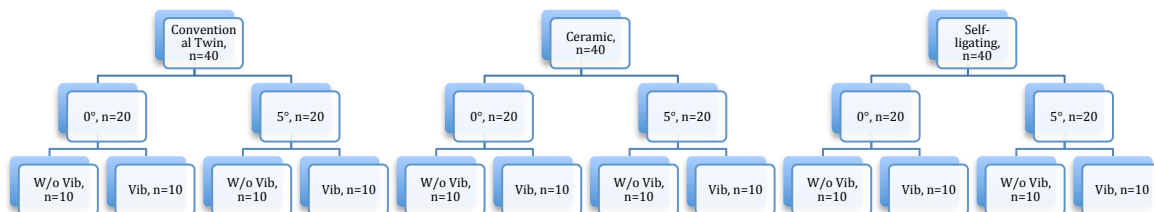
1. There is no difference in the resistance to sliding between brackets of one material and angulation, and a wire when pulsating vibration is applied.
2. There is no difference in the resistance to sliding between different bracket types, with vibration or without.

## Chapter 2: Materials and Methods

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### 2.1. Study

10 trials each, of 3 types of brackets (conventional twin, ceramic, and self-ligating) (American Orthodontics, Sheboygan, WI) with 2 different angulations ( $0^\circ$  and  $5^\circ$ ), were run with and without mechanical vibration for a total of 120 test runs included in this in vitro study. (Figure 1)



**Figure 1. Flow chart of bracket groupings, angulations, and vibration.**

#### 2.1.1. IRB Approval

IRB approval was not required for this study.

### **2.1.2. Ethical Issues**

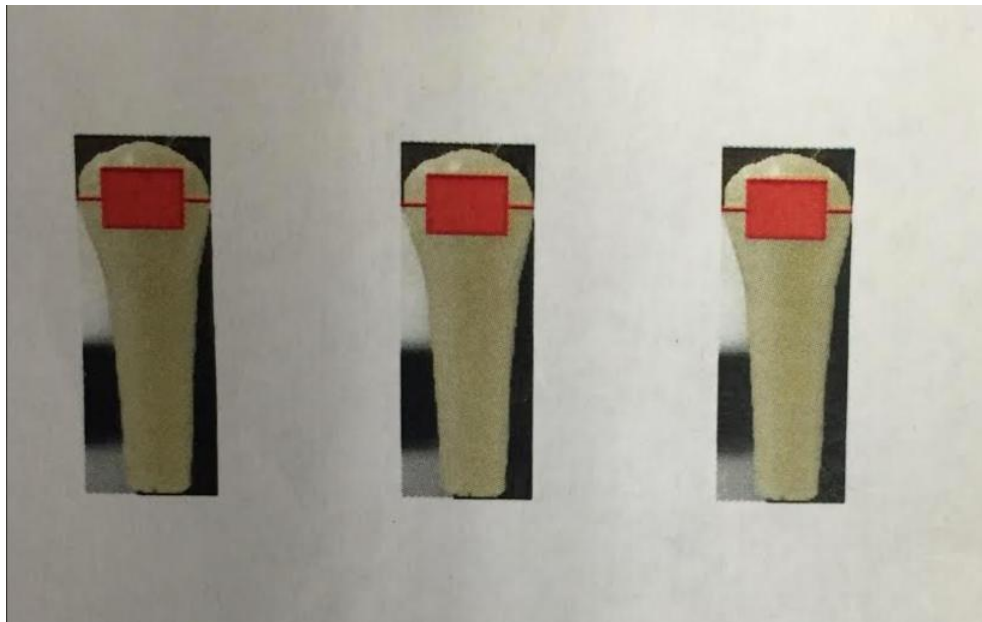
No potential ethical issues could be identified as part of this research study.

### **2.1.3. Grant**

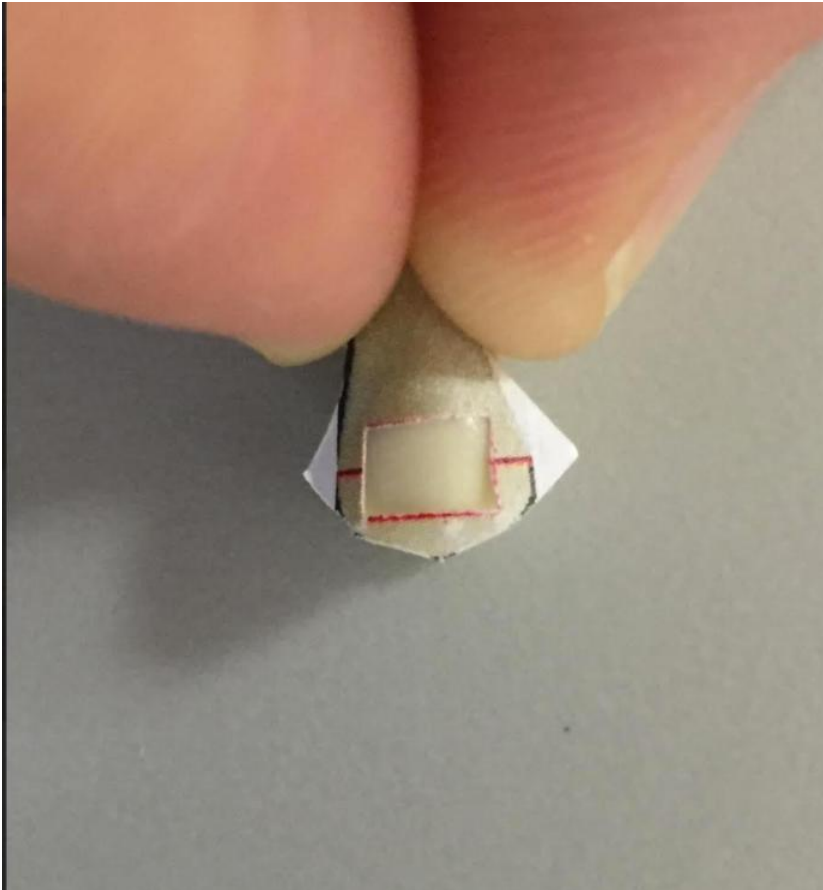
This study was funded by a Health Professions Division grant at Nova Southeastern University.

## **2.2 Sample Preparation**

In order to standardize bracket location, a photo was taken of the typodont tooth (Kilgore Int., Coldwater, TX) and imported into Photoshop CS6 (Adobe Systems Incorporated, San Jose, CA). A paper template with exact dimensions of the typodont tooth and bracket location was constructed to ensure correct angulation. (Figure 2) The bracket window was cut out and the template was overlaid on the typodont tooth. (Figure 3) For each bracket group, 3 of the 4 teeth were bonded with a 0.022" x 0.028" standard prescription edgewise bracket at 0° and one tooth was bonded with the bracket at 5°.



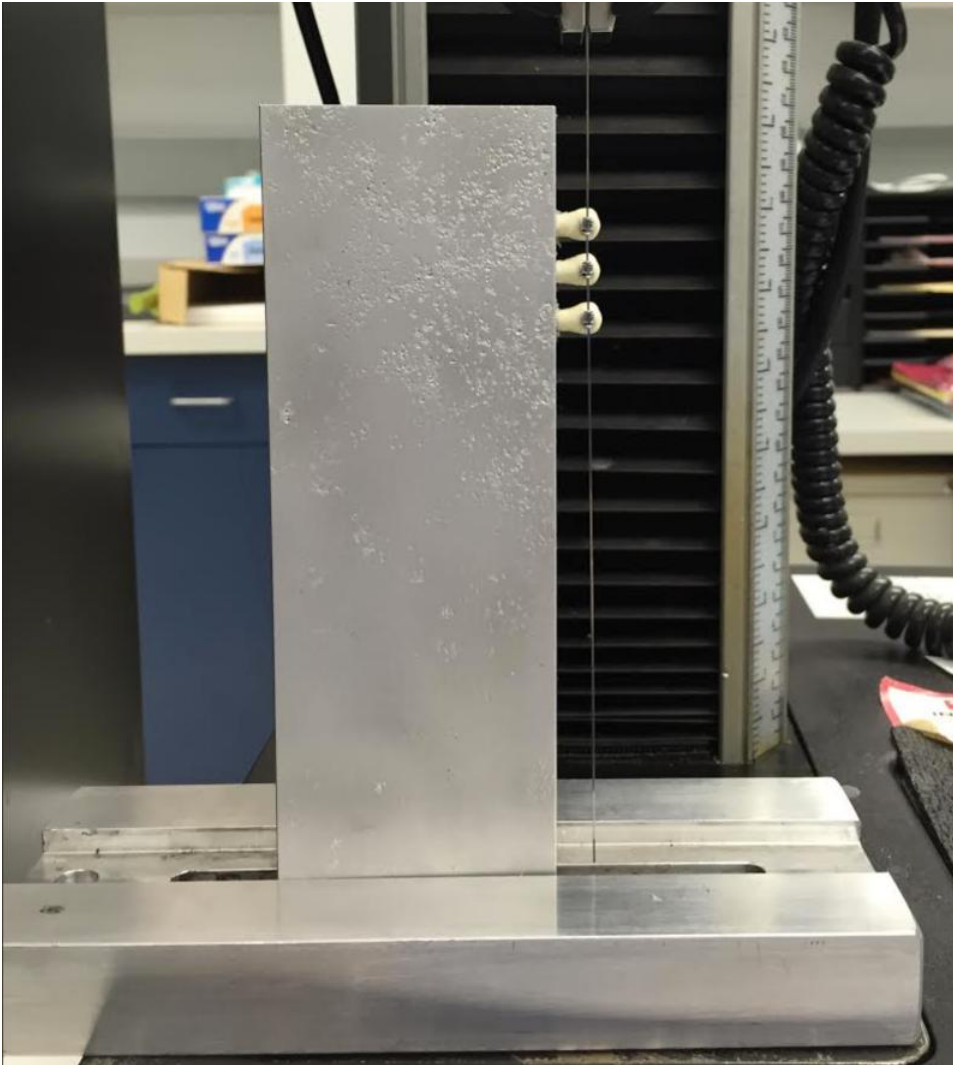
**Figure 2. Typodont tooth paper template with 0° bracket window.**



**Figure 3. Typodont tooth paper template overlaid on tooth.**

A metal scaffold (Vistar Machine Shop, Ft. Lauderdale, FL) was fabricated to house each tooth and to simulate a tooth socket. (Figure 4) Aquasil Ultra XLV wash material PVS (Dentsply Caulk, Milford, DE.) (Figure 5) was inserted into the three sockets to hold the teeth in place. For each group, the three 0° brackets were ligated to a 0.019" x 0.025" SS wire to ensure they were level relative to each other prior to insertion into the PVS (Figure 6). Leveling was confirmed in each direction using the iPhone 6 level (Apple Inc., Cupertino, CA.) (Figure 7)





**Figure 4. Metal scaffold for housing typodont teeth.**

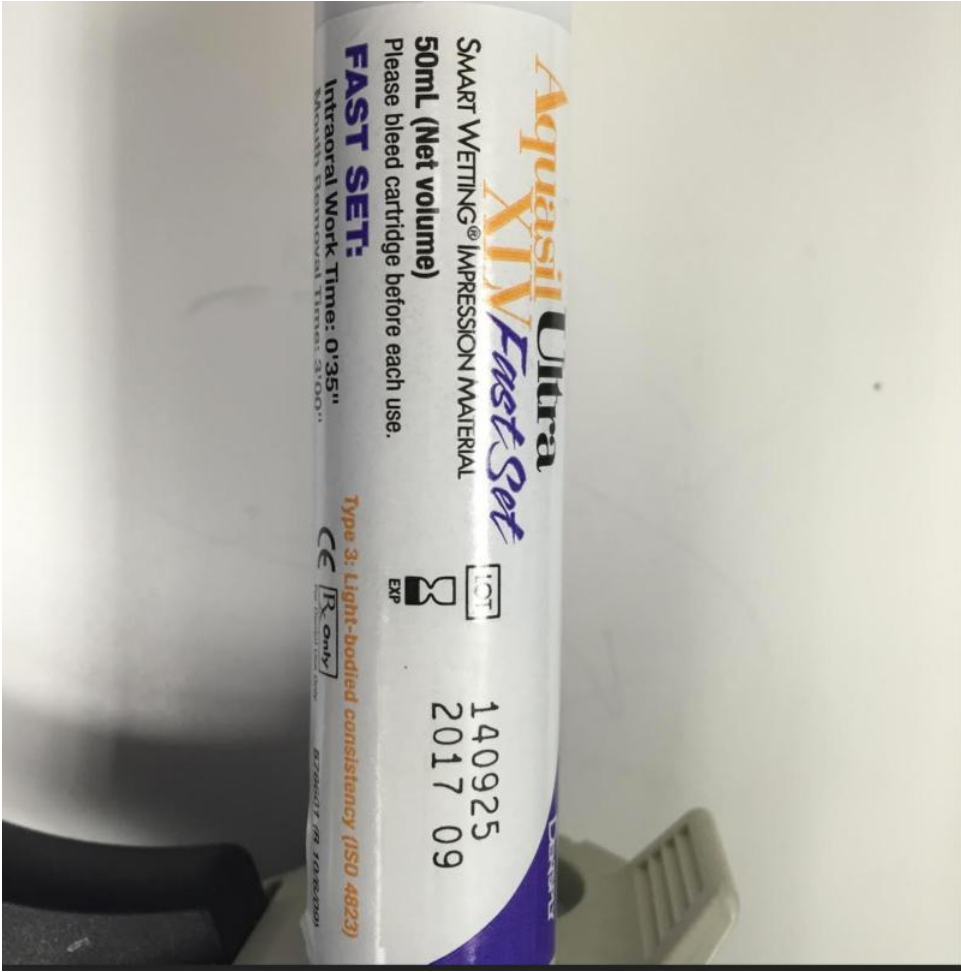
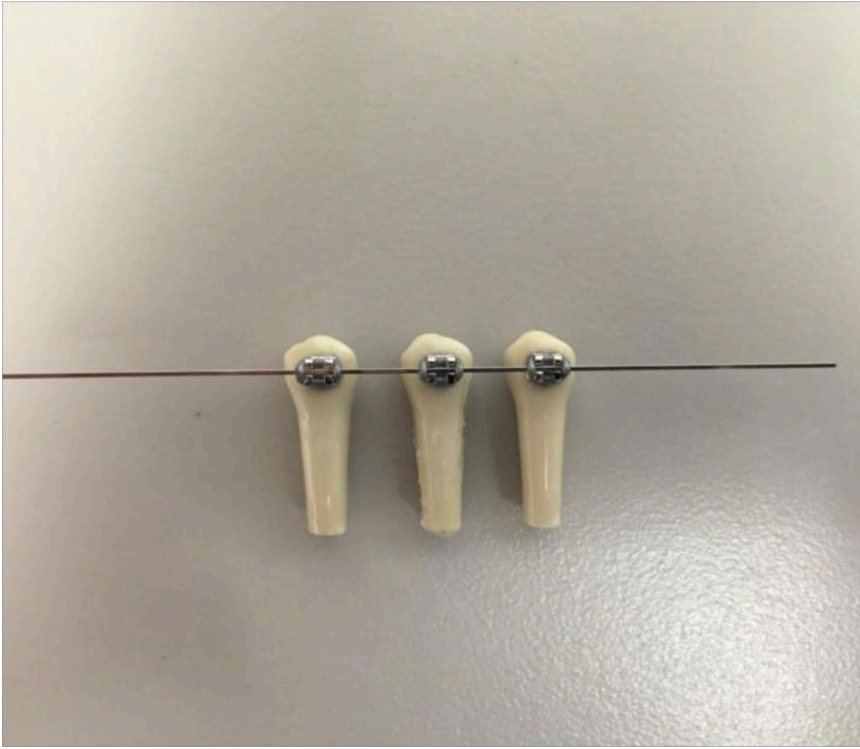
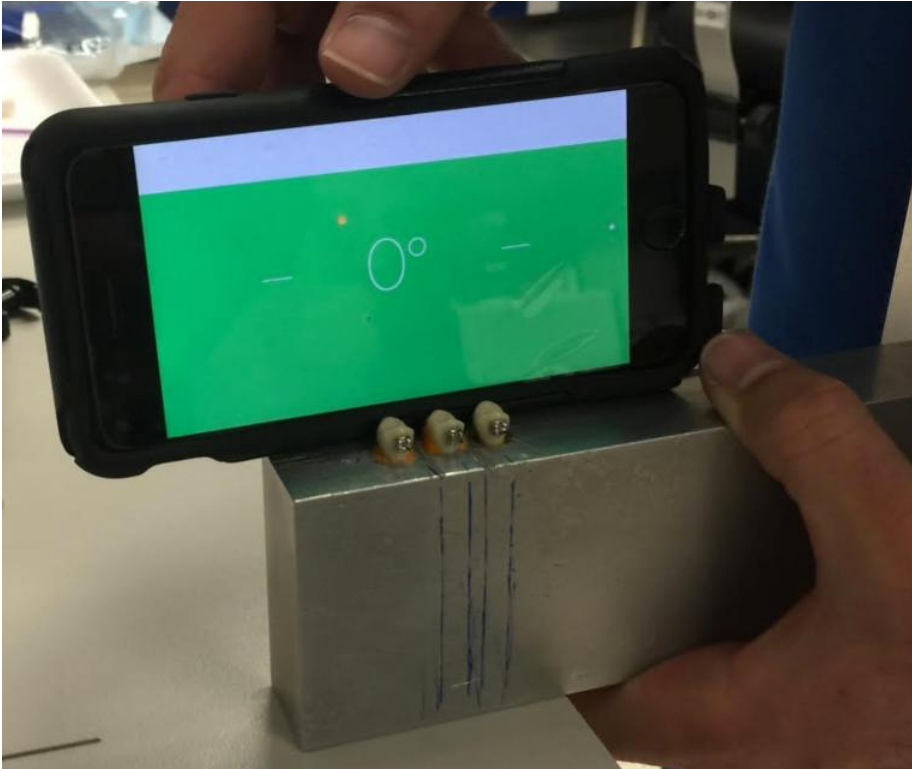


Figure 5. Aquasil Ultra XLV wash material PVS



**Figure 6. 0° brackets ligated to 0.019" x 0.025" arch wire to ensure leveling**



**Figure 7. Leveling confirmed using the iPhone 6 level application.**

A 10cm piece of 0.019" x 0.025" SS wire was placed into the 3 brackets so that 1 cm of wire was left sticking out above the top of the scaffold. All the teeth were ligated with elastik ligatures using the Straight Shooter Ligature gun (TP Orthodontics, Inc., La Porte, IN) (Figure 8) except the middle bracket, which was steel tied. Then, the AcceleDent Aura (OrthoAccel Technologies, Inc., Bellaire, TX) (Figure 9) device was attached to the occlusal surface of the three teeth and held in place with cable ties (Commercial Electric, Home Depot, U.S.A., Inc.) (Figure 10). The cable ties were marked so that they could be replicated and tightened the same amount for each trial run. The occlusal lip of the AcceleDent device was trimmed so it did not interfere with the wire.

### 2.3 Experiment

The metal scaffold was centered underneath the vice grip of the Universal Testing Machine (Instron, Grove City, PA) . (Figure 11) The vice grip was tightened around the arch wire until it was hand tight. A ball of composite was placed on the dial of the vice grip to ensure it was reproducibly tightened to the same level for each trial. (Figure 12) The Universal Testing Machine was set at a crosshead speed of 2.5mm/min, similar to another study.<sup>3</sup>



**Figure 8. TP Orthodontics Straight Shooter Ligature gun.**

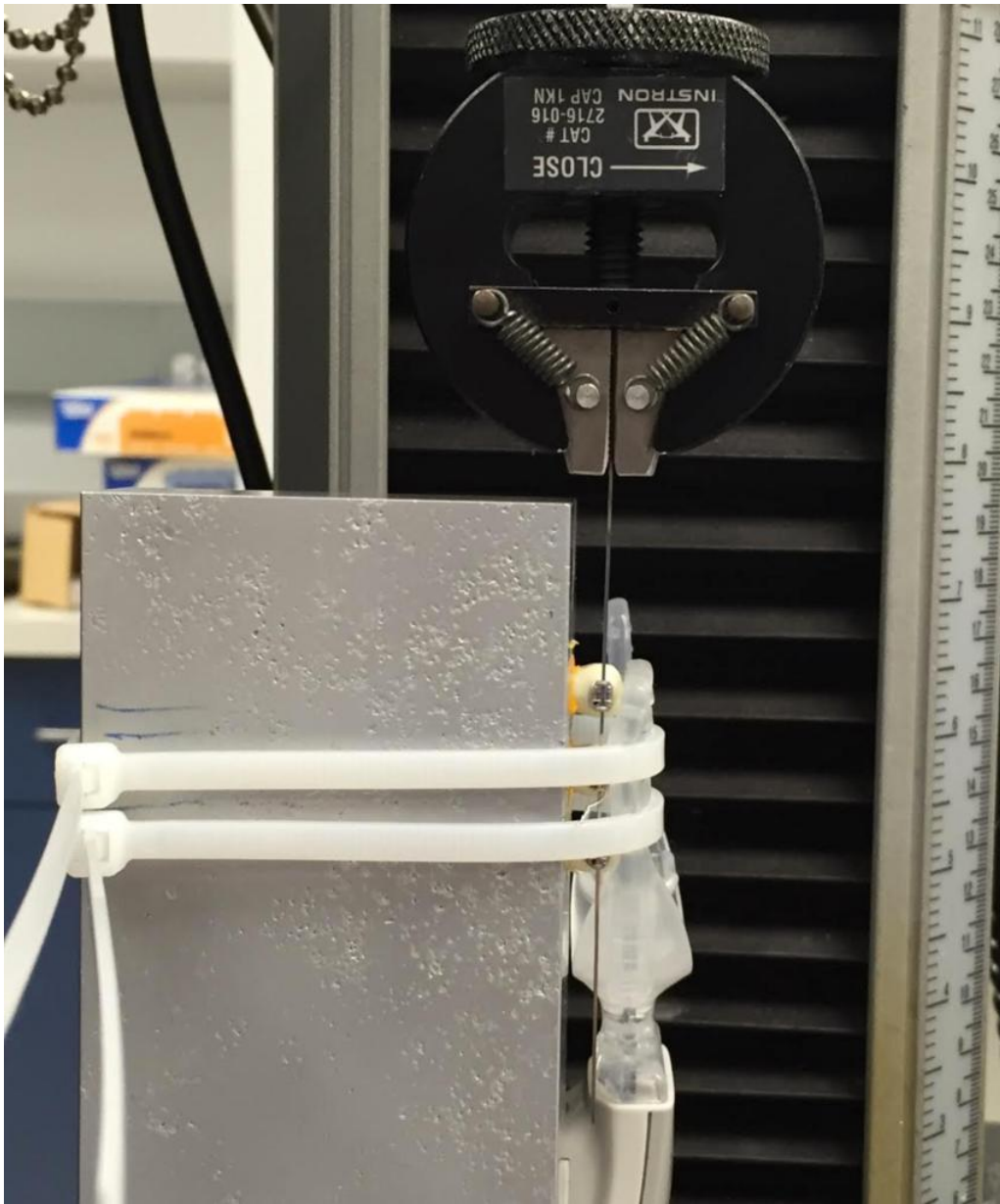


**Figure 9. AcceleDent Aura device.**



**Figure 10. Cable ties holding AccelDent in place against the teeth.**





**Figure 11. Metal scaffold with teeth centered underneath the Universal Testing Machine.**





**Figure 12. Vice grip tightened with composite ball marker in place.**

The Universal Testing Machine was set to run for 620 seconds. Data collection began at the 10 second point. Every 30 seconds a new data set was collected. The AcceleDent was turned on between the 310 and 315 second point, prior to beginning data collection at the 320 second point, and thus applying the 30Hz vibratory force to the system. When the Universal Testing Machine

stopped, 6 data recordings for each data set were taken every 5 seconds (i.e. 10s, 15s, 20s, 25s, 30s, 35s) and the mean of these numbers was recorded. The maximum and minimum values were also recorded. After the trials of the 0° brackets were run, the middle tooth was switched out with the 5° bracketed tooth. This tooth was ligated along with the other two teeth to the wire and the metal scaffold was filled with PVS. Before the PVS setup the wire was removed and the middle tooth was up-righted so its long axis was vertical again, 90° to the plane of occlusion. Since the bracket on that tooth was placed at 5°, this ensured the middle bracket was angulated. A wire was placed in the angulated slot and the iPhone 6 level was used to ensure angulation accuracy (Figure 13). Then, the above process was repeated for data collection.



**Figure 13. Bracket angulation confirmed with iPhone 6 level.**

## **2.4 Statistical Analysis**

A Satterthwaite two-sample t-test was used to test for significance of vibration due to unequal group variances. A two factor ANOVA was run to determine if the bracket type and vibration were significant.

## Chapter 3: Results

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### 3.1. Descriptive Statistics for Each Bracket Group, at Each Angulation, with and without Vibration

The descriptive statistics for each bracket type and each angle and vibration grouping are listed in Table 1. The 5° ceramic grouping did not have any data reported because the resistance to sliding became so great, that the middle bracket was debonded before any trials could be completed. Therefore, the 5° ceramic group was not analyzed. In every other grouping, the maximum resistance to sliding was lower when vibration was applied. The minimum resistance to sliding value was also lower with vibration. The mean frictional resistance between the bracket and arch wire was lower with vibration for every bracket grouping that reported data.

**Table 1. Descriptive Statistics**

| Type          | Angle | Vibration | N  | Mean  | SD    | Min   | Max   |
|---------------|-------|-----------|----|-------|-------|-------|-------|
| Ceramic       | 0     | No        | 10 | 2.05  | 0.09  | 1.89  | 2.15  |
| Ceramic       | 0     | Yes       | 10 | 1.69  | 0.19  | 1.27  | 1.94  |
| Ceramic       | 5     | No        | 10 | ----- | ----- | ----- | ----- |
| Ceramic       | 5     | Yes       | 10 | ----- | ----- | ----- | ----- |
| Self-Ligating | 0     | No        | 10 | 0.07  | 0.04  | 0.02  | 0.15  |
| Self-Ligating | 0     | Yes       | 10 | -0.03 | 0.05  | -0.10 | 0.05  |
| Self-Ligating | 5     | No        | 10 | 2.07  | 0.03  | 2.03  | 2.10  |
| Self-Ligating | 5     | Yes       | 10 | 1.68  | 0.18  | 1.43  | 1.98  |
| Twins         | 0     | No        | 10 | 1.27  | 0.10  | 1.13  | 1.45  |
| Twins         | 0     | Yes       | 10 | 0.61  | 0.18  | 0.35  | 0.86  |
| Twins         | 5     | No        | 10 | 1.87  | 0.20  | 1.44  | 2.08  |
| Twins         | 5     | Yes       | 10 | 1.54  | 0.19  | 1.36  | 1.96  |

### 3.2. Statistical Analysis of Data

There was a significant difference among every group that reported data when vibration was applied, as shown in Table 2. Vibration reduced the mean resistance to sliding for the following groups: 0° ceramic, 0° self-ligating, 0° twin, 5° self-ligating, and 5° twin.

Using a Satterthwaite two-sample t-test we find the following differences:

**Table 2. Multiple Comparisons Tests**

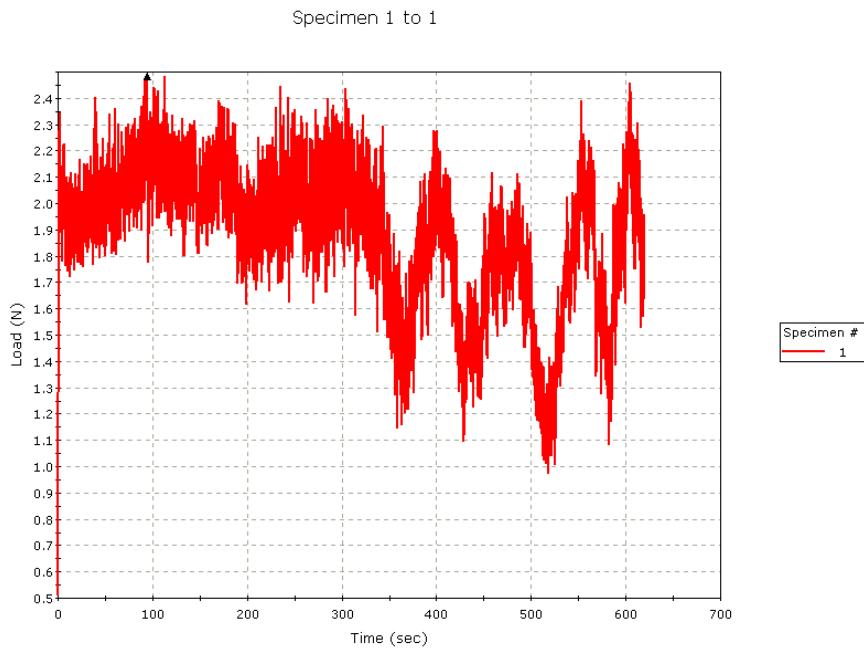
| Angle | Material      | Vibration |       |      |       |       |      | 95% CI for Mean Difference | Diff. | t     |
|-------|---------------|-----------|-------|------|-------|-------|------|----------------------------|-------|-------|
|       |               | No        |       |      | Yes   |       |      |                            |       |       |
|       |               | M         | SD    | N    | M     | SD    | N    |                            |       |       |
| 0     | Ceramic       | 2.05      | 0.08  | 10   | 1.69  | 0.19  | 10   | 0.21,0.50                  | 0.35  | 5.44* |
| 5     | Ceramic       | -----     | ----- | ---- | ----- | ----- | ---- | -----                      | ----- | ----- |
| 0     | Self-Ligating | 0.07      | 0.03  | 10   | -.03  | 0.04  | 10   | 0.05,0.14                  | 0.10  | 5.23* |
| 5     | Self-Ligating | 2.07      | 0.03  | 10   | 1.68  | 0.17  | 10   | 0.26,0.52                  | 0.39  | 6.81* |
| 0     | Twins         | 1.26      | 0.10  | 10   | 0.61  | 0.18  | 10   | 0.51,0.79                  | 0.65  | 9.80* |
| 5     | Twins         | 1.86      | 0.20  | 10   | 1.54  | 0.15  | 10   | 0.14,0.50                  | 0.32  | 3.76* |

*Note:* Satterthwaite approximation employed due to unequal group variances.

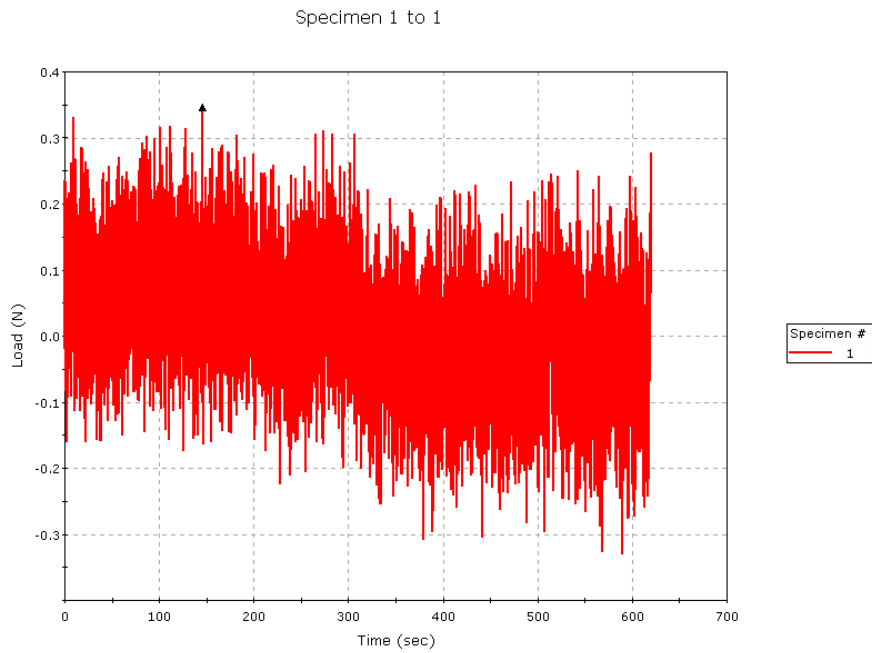
\* p < 0.05.

In looking at the resistance to sliding when the brackets were at the 0° angle, the mean resistance to sliding was greatest for the ceramic brackets without vibration, and the least for self-ligating brackets with vibration. The graphs of the raw data for all three bracket types are shown in Figures 14,15, and 16. Table 3 shows the mean values for all three types of brackets, with and without vibration. The highest mean value, 2.05, was seen in the ceramic

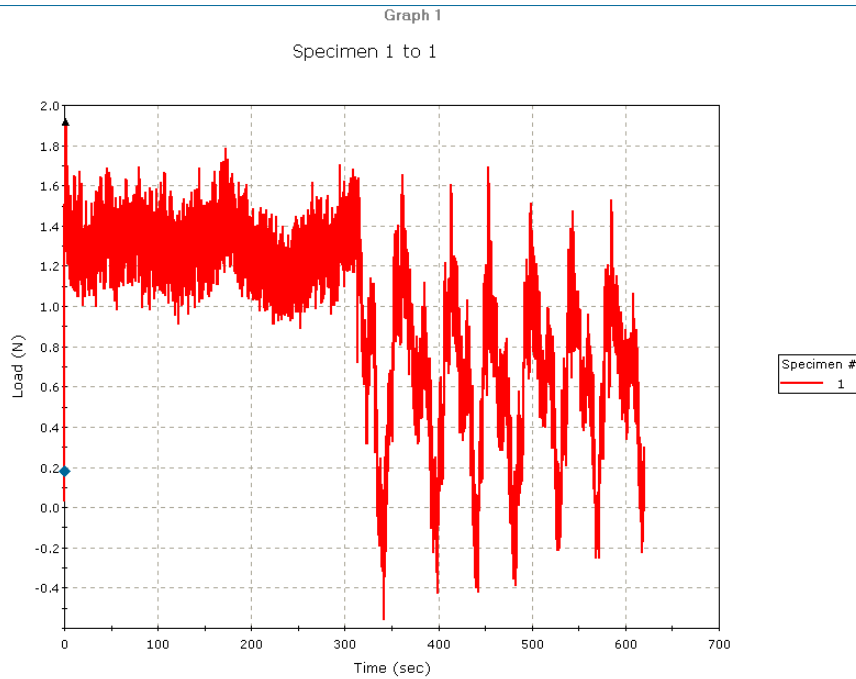
brackets without vibration. The self-ligating brackets with vibration had the lowest mean value, at -0.03. Table 4 shows that the bracket type and the vibration factor were determined to cause significant differences. Figure 17 also depicts these differences.



**Figure 14. Resistance to sliding of 0° ceramic brackets with and without vibration**



**Figure 15. Resistance to sliding of 0° self-ligating brackets with and without vibration**



**Figure 16. Resistance to sliding of 0° twin brackets with and without vibration**

**0° angle**

The means and descriptive statistics are presented in Table 3. The two-factor analysis of variance showed a significant main effect for the type of bracket factor,  $F(2,54) = 1118.89, p < 0.05$ ; a significant main effect for the vibration factor,  $F(1,54) = 135.33, p < 0.05$ ; and a significant interaction between type of bracket factor and vibration,  $F(2,54) = 25.17, p < 0.05$ ." Results from the Tukey-HSD test are found in Table 4 and Figure 1.

**Table 3. Descriptive Statistics**

| Type          | Vibration | N  | Mean  | SD   | Min   | Max  |
|---------------|-----------|----|-------|------|-------|------|
| Ceramic       | No        | 10 | 2.05  | 0.09 | 1.89  | 2.15 |
| Ceramic       | Yes       | 10 | 1.69  | 0.19 | 1.27  | 1.94 |
| Self-Ligating | No        | 10 | 0.07  | 0.04 | 0.02  | 0.15 |
| Self-Ligating | Yes       | 10 | -0.03 | 0.05 | -0.10 | 0.05 |
| Twins         | No        | 10 | 1.27  | 0.10 | 1.13  | 1.45 |
| Twins         | Yes       | 10 | 0.61  | 0.18 | 0.35  | 0.86 |



**Table 4. Results - Tukey HSD Test**

| Comparisons                        | Difference | Lower<br>95% CI | Upper<br>95% CI | P-Value |
|------------------------------------|------------|-----------------|-----------------|---------|
| Self-Ligating:No - Ceramic:No      | -1.98      | -2.14           | -1.82           | 0.00    |
| Twins:No - Ceramic:No              | -0.78      | -0.94           | -0.62           | 0.00    |
| Ceramic:Yes - Ceramic:No           | -0.36      | -0.52           | -0.20           | 0.00    |
| Self-Ligating:Yes - Ceramic:No     | -2.08      | -2.24           | -1.92           | 0.00    |
| Twins:Yes - Ceramic:No             | -1.44      | -1.60           | -1.27           | 0.00    |
| Twins:No - Self-Ligating:No        | 1.20       | 1.04            | 1.36            | 0.00    |
| Ceramic:Yes - Self-Ligating:No     | 1.62       | 1.46            | 1.78            | 0.00    |
| Self-Ligating:Yes-Self-Ligating:No | -0.10      | -0.26           | 0.06            | 0.47    |
| Twins:Yes - Self-Ligating:No       | 0.54       | 0.38            | 0.71            | 0.00    |
| Ceramic:Yes - Twins:No             | 0.42       | 0.26            | 0.58            | 0.00    |
| Self-Ligating:Yes - Twins:No       | -1.30      | -1.46           | -1.14           | 0.00    |
| Twins:Yes - Twins:No               | -0.65      | -0.82           | -0.49           | 0.00    |
| Self-Ligating:Yes - Ceramic:Yes    | -1.72      | -1.88           | -1.56           | 0.00    |
| Twins:Yes - Ceramic:Yes            | -1.08      | -1.24           | -0.91           | 0.00    |
| Twins:Yes - Self-Ligating:Yes      | 0.64       | 0.48            | 0.81            | 0.00    |

**Figure 17. Barplot with 95% Confidence Intervals at 0° angle**

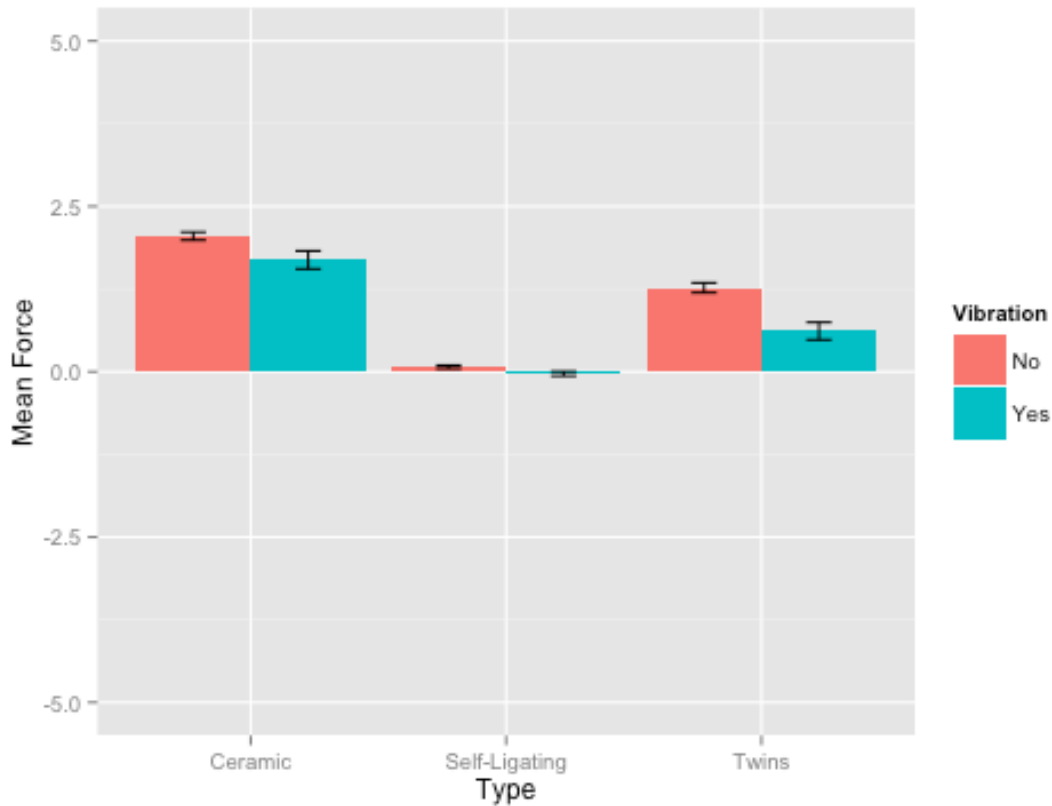
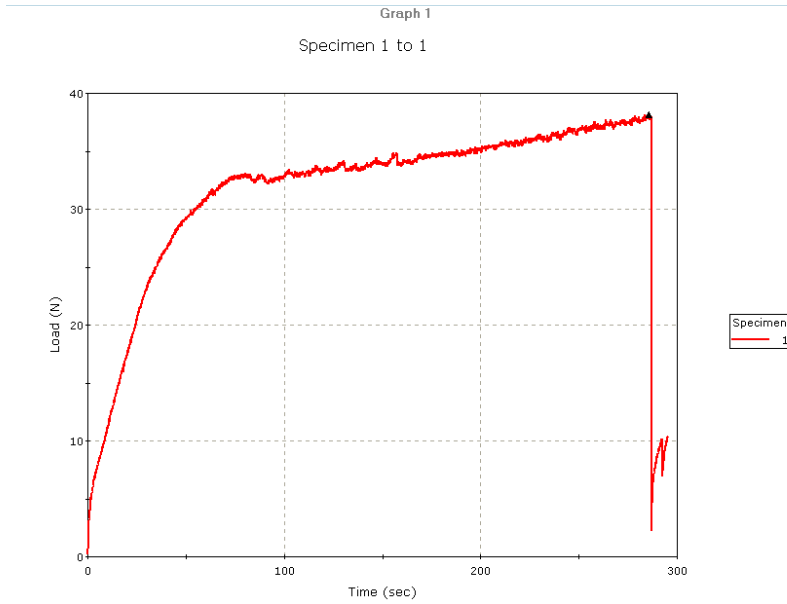
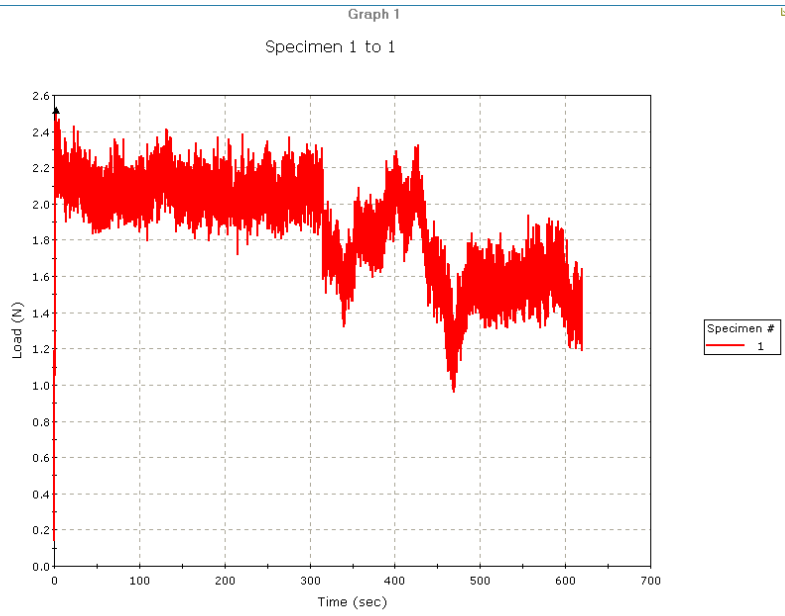


Table 5 shows the mean values for resistance to sliding with brackets at the 5° angle. The graphs of the raw data for all three bracket types are shown in Figures 18,19, and 20. Resistance to sliding was, again, greatest for ceramic brackets and the least for self-ligating brackets. The resistance to sliding of the ceramic brackets was so high, the bracket debonded before data could be recorded. However, when eliminating the ceramic group, the highest mean value, 2.07, was seen in the self-ligating brackets without vibration. The twin brackets with vibration had the lowest mean value, at 1.54. Table 6 shows that the bracket

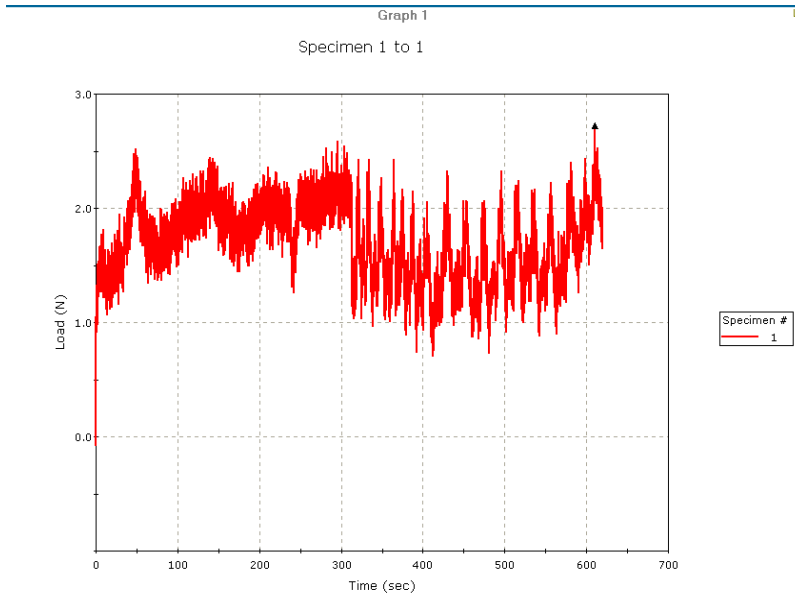
type and the vibration factor were determined to be significant. Figure 21 also depicts these differences.



**Figure 18. Resistance to sliding of 5° ceramic brackets showing bracket debonding**



**Figure 19. Resistance to sliding of 5° self-ligating brackets with and without vibration**



**Figure 20. Resistance to sliding of 5° twin brackets with and without vibration**

**5° angle**

The means and descriptive statistics are presented in Table 5. The two-factor analysis of variance showed a significant main effect for the type of bracket factor,  $F(1,36) = 10.89$ ,  $p < 0.05$ ; a significant main effect for the vibration factor,  $F(1, 36) = 47.68$ ,  $p < 0.05$ ; but no significant interaction between type of bracket factor and vibration,  $F(1, 36) = 0.41$ ,  $p = 0.52$ ." Results from the Tukey-HSD test are found in Table 6 and Figure 2.

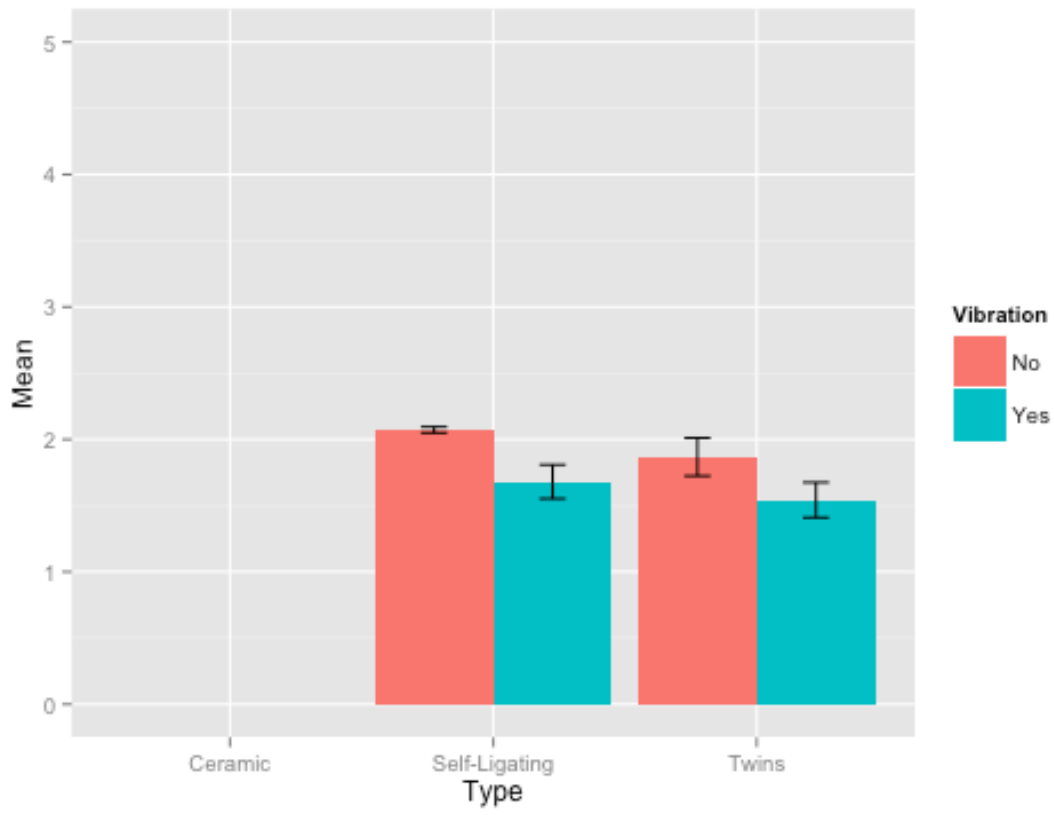
**Table 5. Descriptive Statistics**

| Type          | Vibration | N  | Mean  | SD    | Min   | Max   |
|---------------|-----------|----|-------|-------|-------|-------|
| Ceramic       | No        | 10 | ----- | ----- | ----- | ----- |
| Ceramic       | Yes       | 10 | ----- | ----- | ----- | ----- |
| Self-Ligating | No        | 10 | 2.07  | 0.03  | 2.03  | 2.10  |
| Self-Ligating | Yes       | 10 | 1.68  | 0.18  | 1.43  | 1.98  |
| Twins         | No        | 10 | 1.87  | 0.20  | 1.44  | 2.08  |
| Twins         | Yes       | 10 | 1.54  | 0.19  | 1.36  | 1.96  |

**Table 6. Results - Tukey HSD Test**

| Comparisons                        | Difference | Lower<br>95% CI | Upper<br>95% CI | P-Value |
|------------------------------------|------------|-----------------|-----------------|---------|
| Twins:No-Self-Ligating:No          | -0.20      | -0.40           | -0.01           | 0.04    |
| Self-Ligating:Yes-Self-Ligating:No | -0.39      | -0.59           | -0.19           | 0.00    |
| Twins:Yes-Self-Ligating:No         | -0.53      | -0.73           | -0.33           | 0.00    |
| Self-Ligating:Yes-Twins:No         | -0.19      | -0.38           | 0.01            | 0.07    |
| Twins:Yes-Twins:No                 | -0.33      | -0.52           | -0.13           | 0.00    |

Figure 21. Barplot with 95% Confidence Intervals at 5° angle



## Chapter 4: Discussion

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The purpose of this study was to evaluate the effect of pulsating vibration on the resistance to sliding of a 0.019" x 0.025" stainless steel wire on different orthodontic brackets at different angulations. Brackets were placed at different angulations to replicate a tooth tipping during tooth movement. This often causes binding of the bracket and arch wire, resulting in increased friction.

The maximum and minimum values for all bracket groups were smaller when vibration was added. Adding vibration to the teeth kept the mean resistance to sliding lower, as well. Similar to other vibration studies, vibration decreased the amount of friction between the bracket and arch wire when overcoming static friction.<sup>41-43</sup> One can reasonably assume this result is indicative of vibration decreasing the binding of the corner of the bracket and the arch wire. During orthodontic movement, the bracket tips until it binds against the arch wire and this binding results in more force needed to overcome the static friction.

*Kusy and Whitley*<sup>44, 45</sup> showed that binding and notching of the arch wire and bracket have a greater impact on resistance to sliding than kinetic friction between the two materials once the bracket tips to the point where the wire touches the corners of the bracket on both sides. This angulation is termed the critical angle. Once the angle between the corners of the bracket and arch wire surpass the critical angle, binding takes over and the resistance to sliding increases exponentially. One study using a 0.021" x 0.025" SS wire in 0.022" x 0.028" brackets showed binding to be 94% of what was causing the resistance to



sliding when the bracket was angulated 7°. <sup>46</sup> *Olson et. al.* added vibrations of various frequencies and amplitudes to a 0.017" x 0.025" SS wire being pulled through two different 0.022" x 0.028" brackets. They created a moment in the bracket by attaching a metal arm to the back of the bracket and extending the arm 10mm above the bracket to simulate the center of resistance. A NiTi retraction coil was then attached to the moment arm to simulate canine retraction force. The results showed the amplitude of the vibration had a significant impact on reducing resistance to sliding, i.e., binding. <sup>42</sup>

This study agreed with the results of previous studies <sup>2, 3, 6-9, 11-14, 47, 48</sup> that ceramic brackets cause more friction than conventional twin brackets and self-ligating brackets cause the least, at 0°. Also, as the bracket angulation increased, so did the resistance to sliding. <sup>44-46</sup>

Evaluating the groupings at the 0° bracket angle, ceramic brackets without vibration had the highest mean resistance to sliding. Self-ligating brackets with vibration had the lowest. Both the type of bracket and the vibration factor were shown to have a significant effect on reducing resistance to sliding. These results are in agreement with previous studies because brackets angulated 0° are below the critical angle of binding and vibration has been shown to reduce friction in this scenario. <sup>42, 43, 49-51</sup>

At the 5° angle, ceramic brackets would have had the highest mean resistance to sliding had data been able to be recorded. Due to the resistance to sliding being so high, the force of the Universal Testing Machine debonded the angulated ceramic bracket before the wire started sliding. As a result the self-

ligating brackets without vibration had the highest mean resistance to sliding and the twin brackets with vibration showed the lowest. The reason self-ligating brackets had a higher resistance to sliding than twin brackets in our study can be explained by previous studies relating friction and bracket width.<sup>44, 45, 52</sup> These studies showed increased bracket width increases friction. The self-ligating brackets used in this study had a greater slot width than those twin brackets used. The bracket type and vibration factor were, again, shown to have a significant effect on resistance to sliding.

#### **4.1. Limitations, Implications and Future Studies**

The limitations of this study are due to the materials that were used and the *in vitro* nature of the study. The PVS wash material that was used to fill the sockets of the metal scaffold may have allowed more or less vibration to be transferred to the teeth than the periodontal ligament allows. This may have caused vibration to have a larger or smaller effect on resistance to sliding than it would *in vivo*.

Another possible factor could be the way the vibrations were transferred to the teeth and how the AcceleDent was attached to the occlusal surface of the experimental, typodont teeth. The teeth were aligned in a vertical direction due to the set up of the Universal Testing Machine. As a result, the AcceleDent needed to be held against the teeth, which was done with cable ties in this study. *In vivo* the patient would be resting the mouth guard on the occlusal surface and applying force against the teeth with their own biting pressure. It is possible that the AcceleDent was not held forcefully enough against the teeth and the energy

of the vibration did not fully transfer to the teeth and arch wire. On the other hand, it may have been held down with excessive force, preventing the transfer of vibration to the tooth; therefore, the physiologic movement of the tooth in the socket would not be replicated. This would result in vibration increasing resistance to sliding for the larger bracket angulations.

Another thing to consider is that this experiment was only done with one size arch wire: a 0.019" x 0.025" SS. This wire is typically used in treatment during space closure with sliding mechanics and final alignment. With such a large arch wire the critical angle at which both ends of the bracket bind with the arch wire is very small and causes binding to be the main factor in resistance to sliding. Clinically, the arch should be level before placing a rectangular wire and this size wire would not be placed in the mouth if brackets were angulated 5° from one another.<sup>16</sup> Studies have shown that SS wires lead to reduced kinetic friction between wire and bracket but that they cause the most resistance to sliding when there are deflections in the arch wire.<sup>46, 51</sup> In this case the deflections in the wire were due to the angulated brackets.

The results of this study show that vibration, applied to the occlusal surface of teeth being moved orthodontically, may reduce the resistance to sliding between bracket and arch wire. Brackets should be level and aligned prior to inserting a 0.019" x 0.025" SS wire in a 0.022" x 0.028" bracket. Therefore, applying pulsating vibration to the teeth via the AcceleDent Aura device may be helpful in decreasing the resistance to sliding during space closure. In turn, this could reduce orthodontic treatment time. However, the results of an *in vivo* study

done by *Woodhouse et al.*<sup>30</sup>, showed that vibration had no significant impact on reducing treatment time during the leveling and aligning stage. Ultimately, future studies need to be done *in vivo* to clarify what effect, if any, pulsating vibration has, on the treatment time. As *Kusy* cautions, although vibration might help an arch wire release from a notched wire region due to bracket angulation, its net effect on resistance to sliding is probably equal to zero.<sup>40</sup>

## **Chapter 5: Conclusions**

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Pulsating vibration provided by the AcceleDent Aura device significantly reduced the resistance to sliding of a 0.019" x 0.025" SS arch wire and orthodontic brackets *in vitro*. The bracket material also significantly influenced the resistance to sliding, with ceramic brackets having the largest resistance to sliding. Vibration from the AcceleDent device decreased resistance to sliding in brackets angulated at 0° and 5°. Ultimately, more *in vivo* studies are needed to prove the clinical significance of any of these claims.

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