Tensile Strength of Elastomeric Ligature Ties Stretched Over Large and Small Orthodontic Brackets

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TENSILE STRENGTH OF ELASTOMERIC LIGATURE TIES STRETCHED OVER LARGE AND SMALL ORTHODONTIC BRACKETS

by

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A Thesis submitted to the Faculty of the Graduate School,

Marquette University,

in Partial Fulfillment of the Requirements for

the Degree of Master of Science in Orthodontics

Milwaukee, Wisconsin

August 2020

Abstract

TENSILE STRENGTH OF ELASTOMERIC LIGATURE TIES STRETCHED OVER LARGE AND SMALL ORTHODONTIC BRACKETS

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Objective:
The purpose of this research was to investigate whether or not the larger required stretch of elastomeric ligature ties to secure an orthodontic wire into a larger sized bracket would lead to a more significant loss in tensile strength than if a smaller bracket size was used that required less of a stretch for placement of the elastomeric ligature.

Methods:
Maximum tensile strengths of elastomeric ligature ties from American Orthodontics and Dentsply Sirona were measured and compared after incubation for 4 weeks at 37±1ºC under the following conditions: Unstretched dry, unstretched in artificial saliva, stretched and tied over a small orthodontic bracket (Forestadent Microsprint .018-inch slot lower right incisor bracket) dry, stretched and tied over a small orthodontic bracket in artificial saliva, stretched and tied over a large orthodontic bracket (American Orthodontics Master Series .022-inch slot upper right central incisor) dry, and stretched and tied over a large orthodontic bracket in artificial saliva. A three-way 2x3x2 ANOVA (Brand, Stretch Magnitude, and Artificial Saliva) analysis was performed at $\alpha = 0.05$ on a sample of 240 elastomeric ligatures to determine the effect of different brands, magnitude of stretch, and presence of artificial saliva on maximum tensile strength after 4 weeks of incubation at 37ºC. Tukey's Honestly Significant Difference test was conducted to determine statistical difference between the maximum tensile strength of unstretched, small magnitude of stretch, and large magnitude of stretch elastomeric ligatures.

Results:
No statistically significant difference in maximum tensile strength between American Orthodontics and Dentsply Sirona elastomeric ligature ties ($p = 0.1081$) was found. Presence of artificial saliva resulted in a significant reduction in maximum tensile strength ($p < 0.0001$) between samples tested at the same stretch magnitude. Stretched elastomeric ligature ties resulted in a significantly lower maximum tensile strength than unstretched elastomeric ligatures. The maximum tensile strength in elastomeric ligatures stretched over a small magnitude was not statistically significantly different from that of ligatures stretched over a larger magnitude.

Conclusions:
Elastomeric ligature ties stretched over bracket wings show a significant loss of tensile strength after 4 weeks when compared to unstretched ligature ties. There was no significant statistical difference between elastomeric ligatures stretched over small and large size brackets.

ACKNOWLEDGMENTS

Shiloh Golden, DMD, MS

I would like to thank Dr. David Berzins for his expertise and help with designing and conducting this research project. This would not have been possible without your help.

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CHAPTER 1

INTRODUCTION

Orthodontists have different preferences for bracket sizes, as small and large brackets have different advantages and disadvantages during orthodontic treatment. Elastomeric ligature ties are one of the most common ways to secure orthodontic archwires into bracket slots due to ease of use and the ability of patients to select different colors. Many studies have investigated the force decay of elastomeric chains used in orthodontic space closure, and the effect that pre-stretching has on this force decay. Elastomeric ligature ties are made of the same lightly cross-linked long-chain polyurethane material as elastomeric chains, but different factors that affect force decay or tensile strength of individual elastomeric ligatures have been tested in only a few studies. Currently, it is not known whether or not the larger required stretch in distance of an elastomeric ligature tie to secure a wire into a larger bracket would lead to a significantly greater loss in tensile strength than if a smaller bracket size was used that required less of a stretch. This is important because if a wire is not adequately secured within the bracket slot, initial alignment of crowded teeth may be impeded, and the desired prescription of the bracket may not be fully expressed when larger wires are used later in treatment. Another significant implication of stretching elastomeric ligatures is that a potential reduction in tensile strength could lead to more tearing of the ligatures between appointments, which also impedes tooth movement and expression of bracket prescription, as the orthodontic archwire would no longer be secured into the bracket slot.

CHAPTER 2

REVIEW OF LITERATURE

Orthodontic elastomers are polyurethane materials composed of long chained, lightly cross-linked –(NH)-(C=O)-O- structural units, and are very commonly used in everyday treatment due to their speedy placement and ease of use. Elastomeric chains are used to facilitate tooth movement such as space closure, correction of dental midlines, and movement of impacted teeth, while elastomeric ligatures are used to secure orthodontic archwires into bracket slots. Elastomers are subject to force decay, also known as stress relaxation, when subjected to a fixed amount of stretch over a period of time. Though the minimum amount of force needed from an elastomeric ligature for wire engagement has not been quantified and likely varies with different bracket and wire dimensions, force decay is important because it reduces the amount of force the ligature is providing to secure the archwire into the bracket slot, possibly resulting in inadequate wire engagement.. According to a literature review by Baty et al. (1994), studies have shown that a force decay of 50-70% occurs within the first 24 hours after stretching, which continues at a slower rate for 2-3 more weeks. After 3 weeks, only 30-40% of the original force of the elastomeric ligature is retained (Baty et al., 1994). As a result of this force decay, orthodontic elastomers often fail to fully engage archwires into bracket slots.

Many studies on the factors that affect force decay and tensile strength of orthodontic elastomers have been reported Among those conditions tested for their effect on force decay and tensile strength were different colored elastomeric ligatures, exposure to different disinfectants, exposure to artificial saliva, exposure to in vivo oral conditions, and stretch magnitude of elastomeric chains and ligatures.

Effect of different colored elastomeric chains on force decay

Different colors were added to elastomeric ligature ties to provide esthetics to orthodontic brackets and to increase patient excitement about orthodontic treatment. The effect of different colored elastomeric chains on tensile strength was tested by Baty et al. (1994). The authors subjected 4 colors of elastomeric chain from 3 different brands to the following conditions at 37±0.5ºC: air, distilled water, and artificial saliva. The amount of stretch required to produce 150 g and 350 g of force was then tested for each brand, color, and exposure condition at the following time intervals using a universal testing machine: immediately, 1 hour, 4 hours, 24 hours, 1 week, 2 weeks, and 3 weeks. The authors found that the amount of stretch required to generate 150 g and 300 g of force increased after 4 hours and 24 hours in the distilled water and artificial saliva groups. The brands had varying levels of stretch required to generate the required force when exposed to fluids, but the stretch required to generate 150 g and 300 g by each color within each brand group were not significantly different. This study shows that color does not have an effect on the tensile strength of elastomeric ligatures.

Effect of different disinfectants on tensile strength of elastomeric ligatures

Different amounts elastomeric ligature ties, usually 10 or 20, come attached to a ring or stick. Often times, not every elastomeric ligature is needed when securing an archwire, as many orthodontists use bands or brackets with tubes for maxillary and mandibular molars that do not require a ligature to secure the wire within them. Therefore, the remaining elastomeric ligatures can be sterilized via cold sterilization and used at a later date. Disinfectants, however, can have an effect on the tensile strength at failure of the elastomeric ligature. Evangelista et al. (2007) tested elastomeric ligatures from 3 different brands, exposing them to 2 different disinfectant solutions at room temperature (22±2ºC) for 10 minutes, 1 hour, 8 hours, 48 hours, 7 days, 14 days, and 28 days. The two disinfectant solutions used were Vital Defense-D, a 9% o-polyphenol and 1% o-benzyl-p-chlorophenol, and Cidexplus, a 3.4% glutaraldehyde solution. The authors found a significant decrease in tensile strength at failure in the ligatures exposed to both disinfectants for 1 hour or longer when compared to ligatures that were not exposed to disinfectants. This is clinically significant because elastomeric ligature ties that were exposed to disinfectant may tear during placement in a new patient.

Effect of Artificial Saliva on Tensile Strength of Elastomeric Ligatures

Artificial saliva is commonly used in in vitro dental studies to simulate the oral environment. Many in vitro studies involving elastomeric ligatures involve the use of artificial saliva as a means to increase external validity, and also develop a baseline comparison to which in vivo studies can refer. Ahrari et al. (2010) studied the effect that incubation in artificial saliva had on the tensile strength of elastomeric ligatures. Five brands of elastomeric ligature ties were tied around standard edgewise maxillary central incisor brackets and stored with or without artificial saliva at 37^{o}C for 28 days. The artificial saliva used was made of 1 g sodium carboxymethylcellulose, 4.3 g xylitol, 0.1 g potassium chloride, 5 mg calcium chloride, 40 mg potassium phosphate, 1 mg potassium thiocyanate, and 100 g distilled deionized water. After 28 days, the tensile strength of the ligatures was tested using a universal testing machine. The authors found that all elastomeric ligatures incubated in artificial saliva had a decreased tensile strength compared to the control.

Effect of the Oral Environment on Tensile Strength of Elastomeric Ligatures

While artificial saliva is used to simulate the oral environment, it is limited in doing so due to its inability to replicate intraoral lipids, enzymes, proteins, temperature, pH fluctuation, and the various foods and drinks people ingest. Guimaraes et al. (2013) studied the changes in the tensile strength of elastomeric ligatures aged for 1, 2, 3, and 4 weeks in vivo in the oral environment. The tensile strength of the elastomeric ligatures was tested using a universal testing machine, and the surface characteristics of the elastomeric ligatures were analyzed using a scanning electron microscope. The ultimate tensile strength of the elastomeric ligatures progressively decreased from 1 to 4 weeks, while the surface degradation of the elastomeric ligatures increased progressively from 1 to 4 weeks. The authors suggested that the degradation of the elastomeric ligature was mostly due to hydrolysis. According to Graber et al. (2017), this loss of force is greater in-vivo than in-vitro due to degradation intraorally from temperature change, pH variation, fluoride rinses, proteins and enzymes, lipid absorption by the polyurethanes, and more. This is important because wire engagement and tooth movement could be impeded if elastomeric ligature ties are not replaced in a timely manner.

Effect of Stretching of Elastomeric Ligatures on Tensile Strength

The effect that stretching of elastomers has on tensile strength is widely studied due to the various applications elastomers have for use in orthodontic treatment. Elastomers can be used for other things such as tooth separation, space closure, and midline correct in addition to securing wires into brackets.

Mohammadi et al. (2015) studied the force decay of elastomeric ligature ties in an active tieback state. Active tiebacks are stretched in combination with stainless steel ligatures to close space between teeth. In this study, 3 brands of elastomeric ligatures were stretched to 100% and

150% of their inner diameter (this is the stretch recommended for use in active tieback state clinically), incubated at 37ºC, and measured for force decay at the following time intervals: 3 minutes, 14 hours, 1 week, 2 weeks, 3 weeks, and 4 weeks. The authors found a 29%-63% loss of force after 24 hours, with only 19-48% of the initial force remaining after 4 weeks. This indicates that stretched elastomeric ligatures lose the force they exert over time.

In an attempt to replicate the stretch of an elastomeric ligature tied to a malpositioned tooth at the beginning of treatment, Aminian et al. (2015) tested the force decay and tensile strength of 2 brands of elastomeric ligature ties that were unstretched, uniformly stretched, point stretched 1 mm, and point stretched 3 mm while being incubated at 37±1ºC. Tensile strength was measured using a universal testing machine for each brand initially and at 24 hours, 2 weeks, 4 weeks, and 8 weeks to determine the rate of force decay and residual tensile strength. The authors found that most of the force decay occurred after 24 hours and slowed up to 8 weeks. The elastomers that were uniformly stretched had a lower initial and final tensile strength than those elastomeric ligatures that were point stretched. The elastomeric ligatures that were point stretched had greater force decay than the uniform stretch group. These results are clinically significant because they show that a partial stretch that would be seen with an elastomeric ligature engaging a rotated tooth shows higher tensile strength after 8 weeks than uniformly stretching the elastomer.

Taloumis et al. (1997) tested 7 brands of elastomeric ligatures under the following test conditions: stretched over a steel dowel to simulate the stretch needed to place the ligature over a .022-inch slot maxillary central incisor bracket dry at room temperature (22ºC), and stretched over a steel dowel and incubated in artificial saliva at 37ºC for 28 days. Another group of ligatures was stretched over a steel dowel and incubated at 37ºC in artificial saliva to be tested for tensile strength at 24 hours, 7 days, 14 days, and 28 days to determine the force decay that occurred in each brand. The authors found rapid loss of force within 24 hours with permanent deformation in nearly every brand tested. This is significant because it shows that stretching elastomeric ligatures over a bracket can still lead to a significant loss of force and a lack of wire engagement during initial alignment.

CHAPTER 3

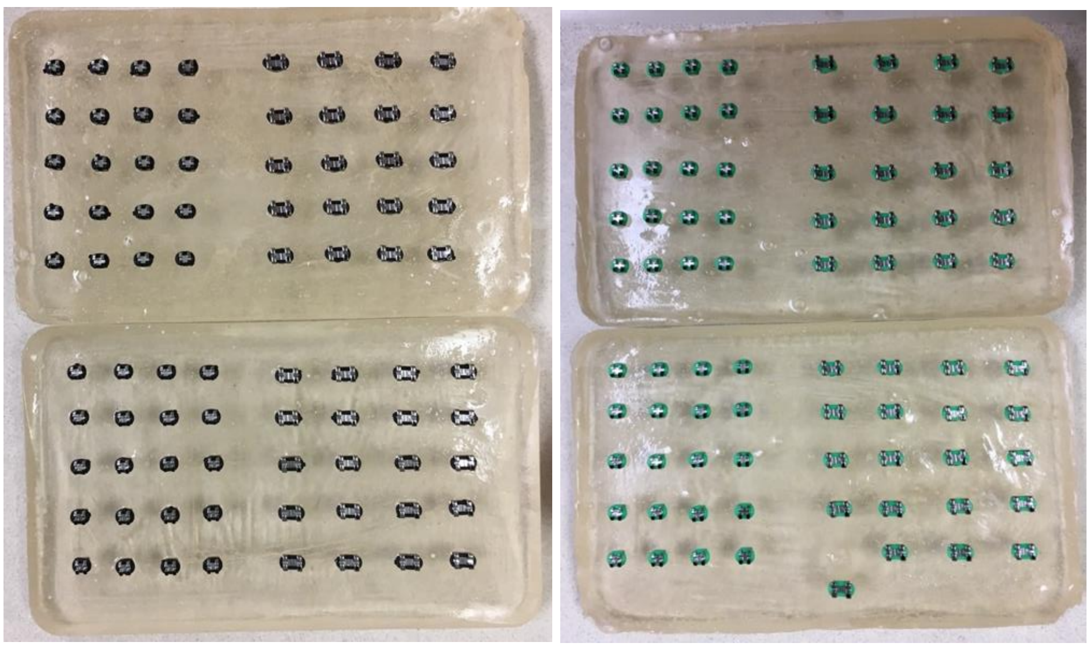
MATERIALS AND METHODS

Two acrylic blocks enclosing .018-inch stainless steel wires with a hook to engage the ligature ties were fabricated for testing tensile strength (Figure 1). The wires were heat treated to increase rigidity.

Figure 1. Testing apparatus: acrylic block enclosing .018-inch stainless steel wire with hook

Four additional acrylic blocks were fabricated to allow brackets to be bonded for controlled placement and removal of elastomeric ligature ties, as well as to allow more consistent exposure to conditions. The acrylic blocks were treated with plastic conditioner and coated with Assure Plus (Reliance) bonding agent. Bracepaste Medium Viscosity Adhesive (American Orthodontics) was spread onto the bracket pads for bonding to the acrylic blocks. Twenty Forestadent Microsprint .018-inch slot mandibular right central incisor brackets (approximate wing perimeter 10.1 mm) and twenty American Orthodontics Master Series .022-inch slot maxillary right central incisor brackets (approximate wing perimeter 13.9 mm) were then placed onto each of the 4 acrylic blocks and light cured to bond them to the test blocks (Figure 2).

Figure 2. Acrylic blocks with Forestadent and American Orthodontics brackets bonded. American Orthodontics elastomeric ligature ties (left, black) and Dentsply Sirona elastomeric ligature ties (right, green) stretched around small (Forestadent Microsprint mandibular right central incisor) and large (American Orthodontics Master Series maxillary right central incisor) bracket wings and secured to the brackets pre-incubation.



One acrylic block with American Orthodontics elastomeric ligature ties secured to brackets was placed into a bin with twenty unstretched American Orthodontics elastomeric ligature ties. One acrylic block with American Orthodontics elastomeric ligature ties secured to brackets was placed into a bin with twenty unstretched American Orthodontics elastomeric ligature ties and artificial saliva. One acrylic block with Dentsply Sirona elastomeric ligature ties secured to brackets was placed into a plastic bin with twenty unstretched Dentsply Sirona elastomeric ligature ties. One acrylic block with

Dentsply Sirona elastomeric ligature ties secured to brackets was placed into a plastic bin with twenty unstretched Dentsply Sirona elastomeric ligature ties and artificial saliva. Through these four blocks, a 2 x 2 table of exposure conditions was created for each bracket type (small/large) and ligature (2 brands) combination whereupon the exposure conditions were stretched/not-stretched and artificial saliva/no artificial saliva. The 4 bins were then incubated at 37±1^{o}C for 4 weeks. After 4 weeks of incubation, the ligature ties were removed from the brackets (Figure 3). To determine the percent stretch when the ligatures were secured to the brackets, photographs were analyzed with image analysis software (ImageJ; U. S. National Institutes of Health). Due to the non-circular shape when placed on the brackets, the inner perimeter, in contrast to inner diameter, was measured and the percent increase from the unstretched to stretched condition was calculated. Next, the maximum tensile strength was tested using an Instron universal testing machine (Figure 4). The elastomeric ligatures were stretched at a rate of 5 mm/minute until failure of the elastomeric ligature tie was reached.

Figure 3. Unstretched, small stretched, large stretched elastomeric ligature ties post-removal from brackets after 4 weeks. American Orthodontics (top, black) and Dentsply Sirona (bottom, green)

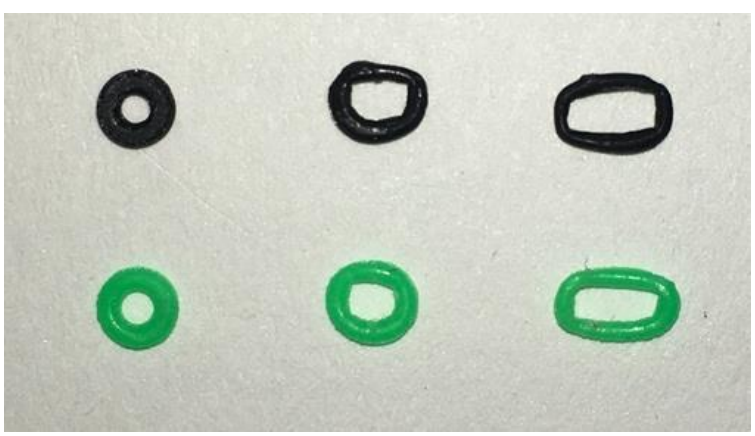
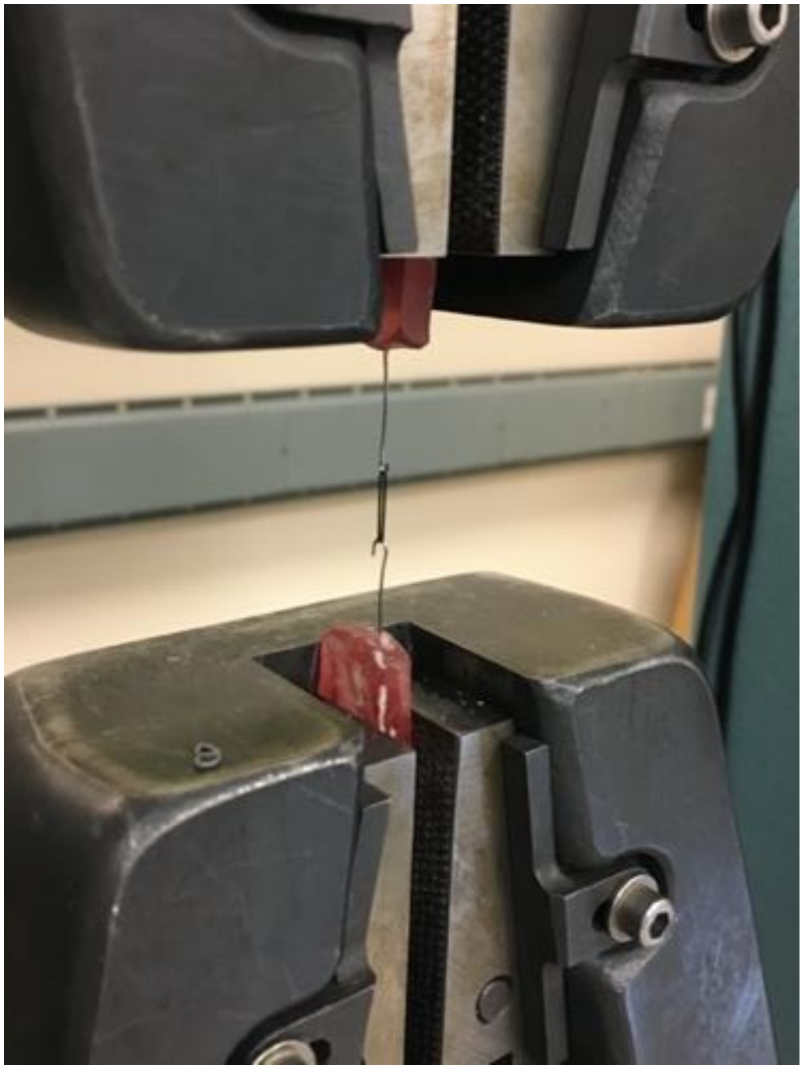


Figure 4. Testing tensile strength using an Instron universal testing machine.



Statistical Analysis: Statistical analysis was performed using SAS version 9.4, SAS Institute, Cary, NC and $\alpha = 0.05$. A three-way 2x3x2 ANOVA (Brand, Stretch Magnitude, and Artificial Saliva) analysis was conducted on a sample of 240 elastomeric ligatures to determine the effect of different brands, magnitude of stretch, and presence of artificial saliva on maximum tensile strength measured in grams of force (gf) after 4 weeks of storage at 37 ± 1^{o}C.

CHAPTER 4

RESULTS

The percent stretch for the Dentsply Sirona ligatures was approximately 70 and 140% for the small and large brackets, respectively, and for the American Orthodontics ligature, it was approximately 110 and 180%. The greater stretch amounts for the American Orthodontics ligature was due to its smaller inner diameter/perimeter prior to stretching compared to the Dentsply Ligature (Figure 3)

Figure 5 displays a typical force versus displacement curve. Maximum tensile strength occurred at a lower stretch displacement (mm) than the stretch displacement (mm) reached at fracture strength. The ultimate tensile strength is the point on the force/displacement curve at which a material is under the maximum amount of stress it can tolerate before it fractures. It should be noted that maximum tensile strength in this context is represented as the maximum tensile force value and not a true strength that takes into account the cross-sectional area of the ligatures. The descriptive statistics and mean maximum tensile strengths of the experimental groups are listed in Table 1.

Figure 5. Force/displacement curve of one sample of American Orthodontics elastomeric ligature stretched to a small magnitude, incubated in artificial saliva for 4 weeks at 37±1°C, and then stretched to failure.

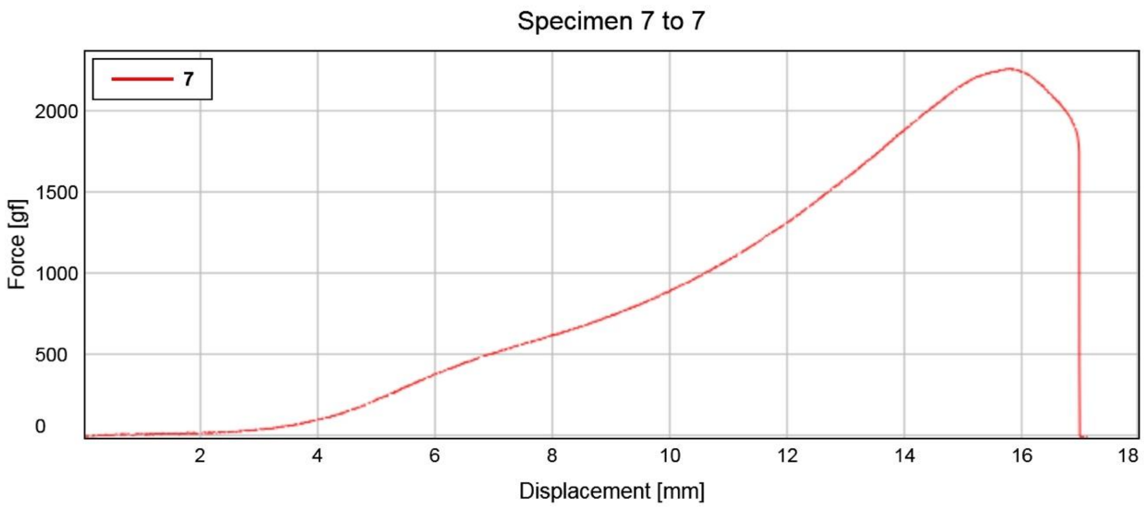


Table 1: Descriptive Statistics of Maximum Tensile Strength.

Brand	Stretch Magnitude	Artificial Saliva	Mean (gf)	Std Dev (gf)	Minimum (gf)	Maximum (gf)
American Orthodontics	**Unstretched**	**No**	2877	213	2543	3391
		Yes	2509	88	2368	2666
	Small Bracket	**No**	2331	270	1815	2690
		Yes	2189	285	1623	2613
	Large Bracket	**No**	2621	210	1986	3017
		Yes	2005	266	1458	2542
Dentsply Sirona	**Unstretched**	**No**	2969	275	2351	3537
		Yes	2292	273	1866	2765
	Small Bracket	**No**	2643	407	1691	3291
		Yes	2185	237	1437	2532
	Large Bracket	**No**	2606	379	1789	3120
		Yes	2179	242	1809	2682

N=20/ligature brand/stretch condition/artificial saliva condition

A three-way 2x3x2 ANOVA was conducted (Table 2) to determine the effect of different brands, magnitude of stretch, and presence of artificial saliva on maximum tensile strength after 4 weeks of incubation at 37±1^{o}C. There was a significant three-way interaction, (*F* (2, 238) = 5.59, *p* = .0043) between the effects of brands, magnitude of stretch, and presence of artificial saliva on maximum tensile strength. To determine the factors responsible for this statistical significance, two-way interactions were analyzed. Interactions between brand and magnitude of stretch (p = 0.0418), brand and presence of artificial saliva (p = 0.0405), and magnitude of stretch and presence of artificial saliva (p = 0.0132) all had significant effects on maximum tensile strength. Further analysis of main effects was needed to determine the reason for statistical significance of the two-way interactions. There was no significant difference in mean maximum tensile strength between brands (p = 0.1081), but stretching (p <0.0001) and presence of artificial saliva (p <0.0001) both significantly reduced mean maximum tensile strength. Finally, Tukey's Honestly Significantly Difference Analysis (Table 3, Figure 6) was conducted to determine statistical difference between the maximum tensile strength of unstretched, small magnitude of stretch, and large magnitude of stretch elastomeric ligatures. A minimum significant difference of 102 grams of force was calculated. The Tukey grouping indicated a statistically significant higher mean maximum tensile strength in unstretched (2662±354 g) compared to stretched elastomeric ligatures. There was no significant difference in mean maximum tensile strength between small (2337±354 g) and large (2353±386 g) stretch magnitudes of elastomeric ligature ties.

Table 2. ANOVA Analysis

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	19913633.25	1810330.3	24.24	<.0001
Error	228	17024613.25	74669.36		
Corrected Total	239	36938246.5			
Source	**DF**	**Anova SS**	**Mean Square**	**F Value**	**Pr > F**
AMEDEN	1	194313.5	194313.5	2.6	0.1081
Magnitude of Stretch	2	5367380.83	2683690.42	35.94	<.0001
Artificial saliva	1	12060615	12060615	161.52	<.0001
AMEDEN*Stretch	2	480974.03	240487.02	3.22	0.0418
AMEDEN*Saliva	1	316899.34	316899.34	4.24	0.0405
Stretch*Saliva	2	658183.63	329091.82	4.41	0.0132
AMEDEN*Stretch*Saliva	2	835266.9	417633.45	5.59	0.0043

Table 3. Tukey's Honestly Statistically Difference Test for Mean Maximum Tensile Strength

Alpha	0.05
Error Degrees of Freedom	228
Error Mean Square	74669.36
Critical Value of Studentized Range	3.3363
Minimum Significant Difference	101.93

Figure 6. Box and whisker plot comparing tensile strength across brands.
(1 = American Orthodontics, 2 = Dentsply Sirona)

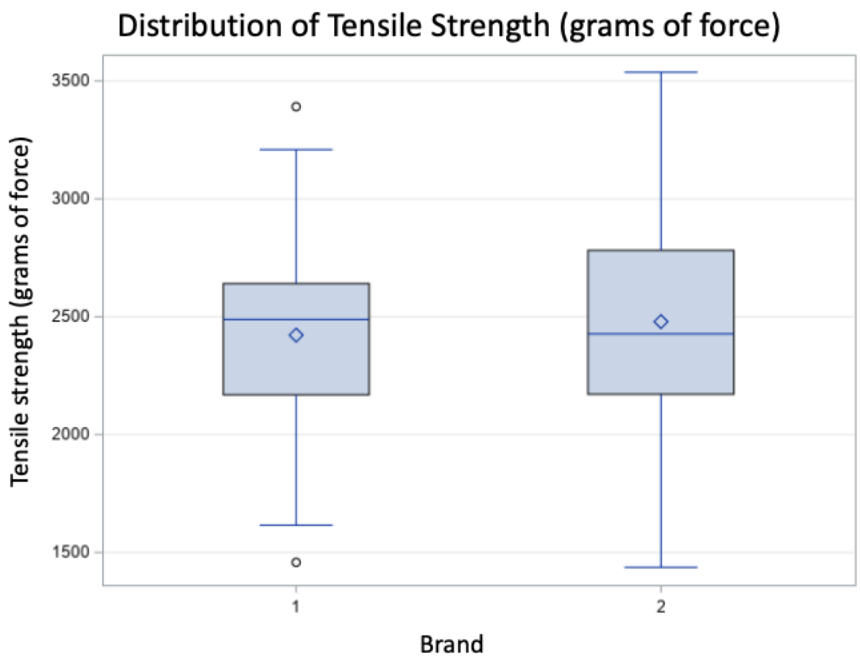


Figure 7. Box and whisker plot comparing tensile strength across stretch magnitude.
(1 = Unstretched, 2 = small stretch magnitude, 3 = large stretch magnitude)

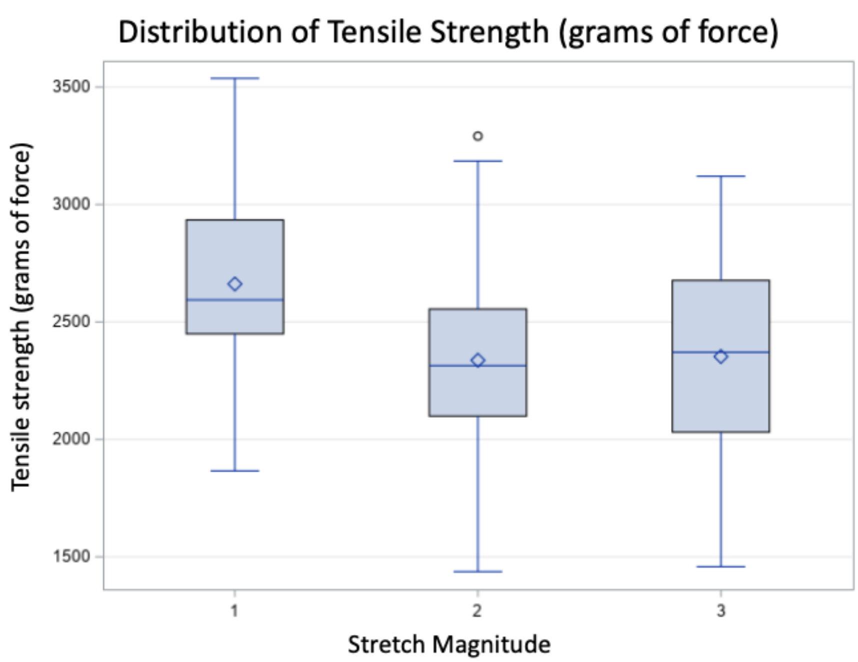


Figure 8. Box and whisker plot comparing tensile strength across presence of artificial saliva. (1 = no artificial saliva, 2 = artificial saliva)

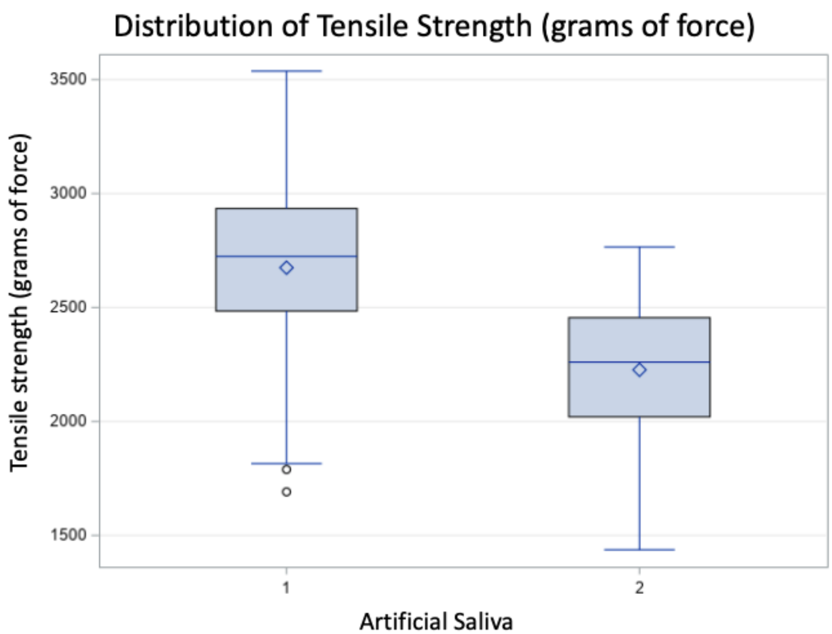


Figure 9. Box and whisker plot comparing tensile strength across stretch magnitudes and brands. (11 = American Orthodontics unstretched, 12 = American Orthodontics small stretch, 13 = American Orthodontics large stretch, 21 = Dentsply Sirona unstretched, 22 = Dentsply Sirona small stretch, 23 = Dentsply Sirona large stretch)

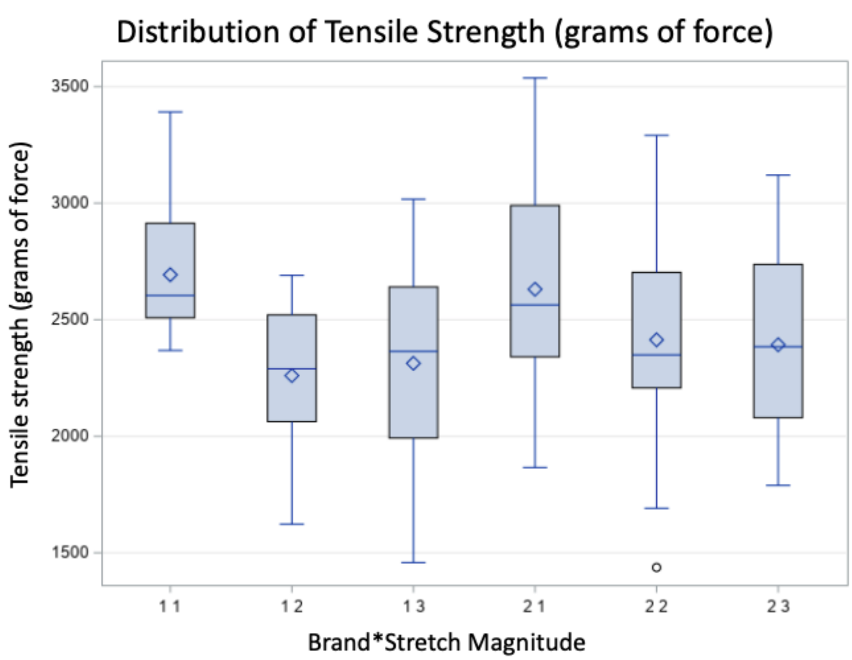


Figure 10. Box and whisker plot comparing tensile strength across presence of artificial saliva and brands. (11 = American Orthodontics dry, 12 = American Orthodontics in artificial saliva, 21 = Dentsply Sirona dry, 22 = Dentsply Sirona in artificial saliva)

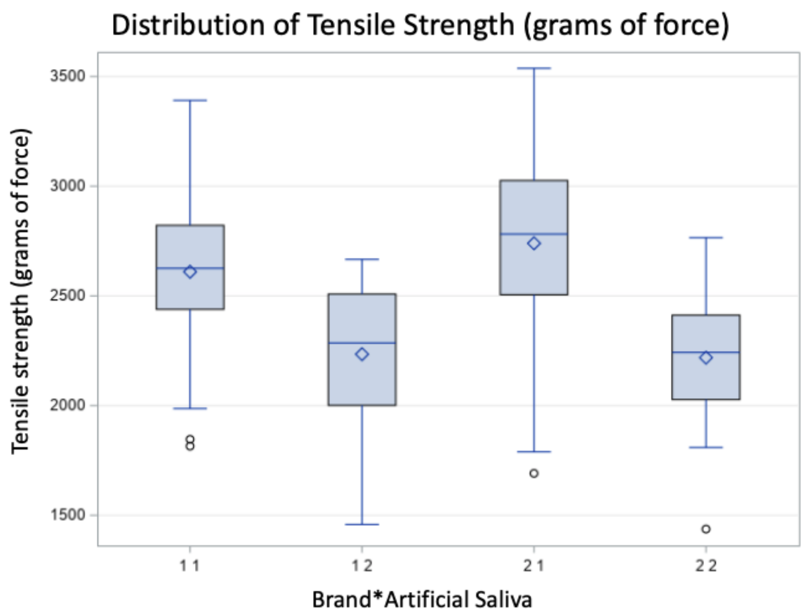


Figure 11. Box and whisker plot comparing tensile strength across stretch magnitude and presence of artificial saliva. (11 = unstretched dry, 12 = unstretched in artificial saliva, 21 = small stretch dry, 22 = small stretch in artificial saliva, 31 = large stretch dry, 32 = large stretch in artificial saliva)

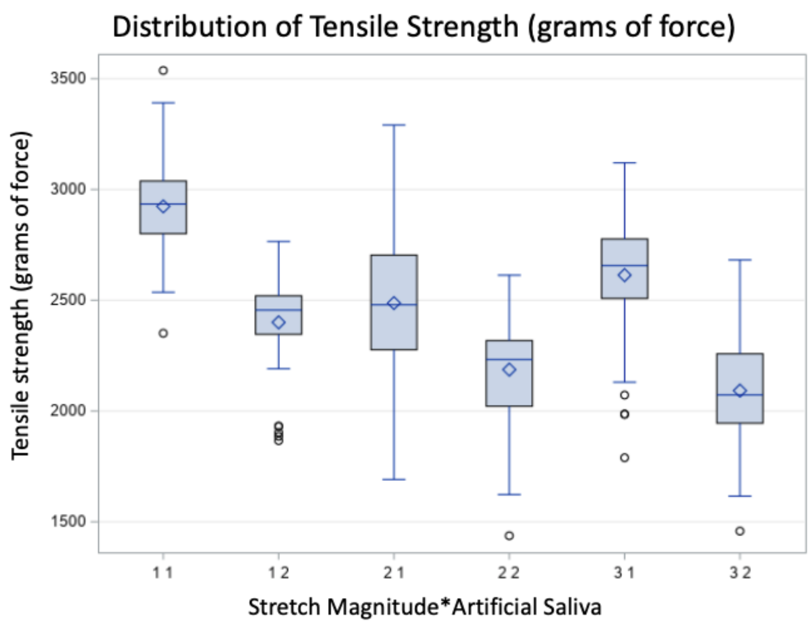


Figure 12. Box and whisker plot comparing tensile strength across brands, stretch magnitude, and presence of artificial saliva (111 = American Orthodontics unstretched dry, 112 = American Orthodontics unstretched in artificial saliva, 121 = American Orthodontics small stretch dry, 122 = American Orthodontics small stretch in artificial saliva, 131 = American Orthodontics large stretch dry, 132 = American Orthodontics large stretch in artificial saliva, 211 = Dentsply Sirona unstretched dry, 212 = Dentsply Sirona unstretched in artificial salvia, 221 = Dentsply Sirona small stretch dry, 222 = Dentsply Sirona small stretch in artificial saliva, 231 = Dentsply Sirona large stretch dry, 232 = Dentsply Sirona large stretch in artificial saliva)

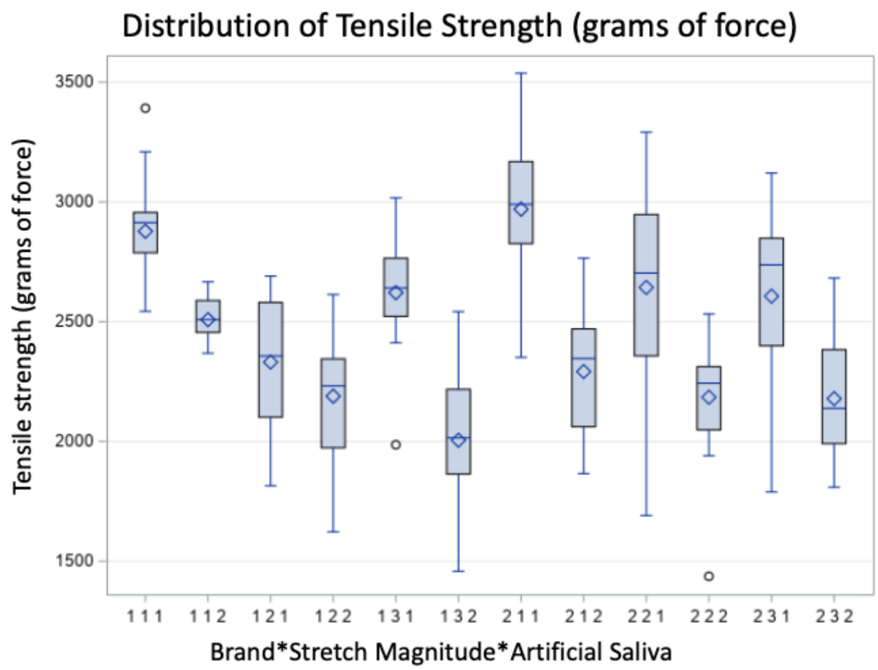
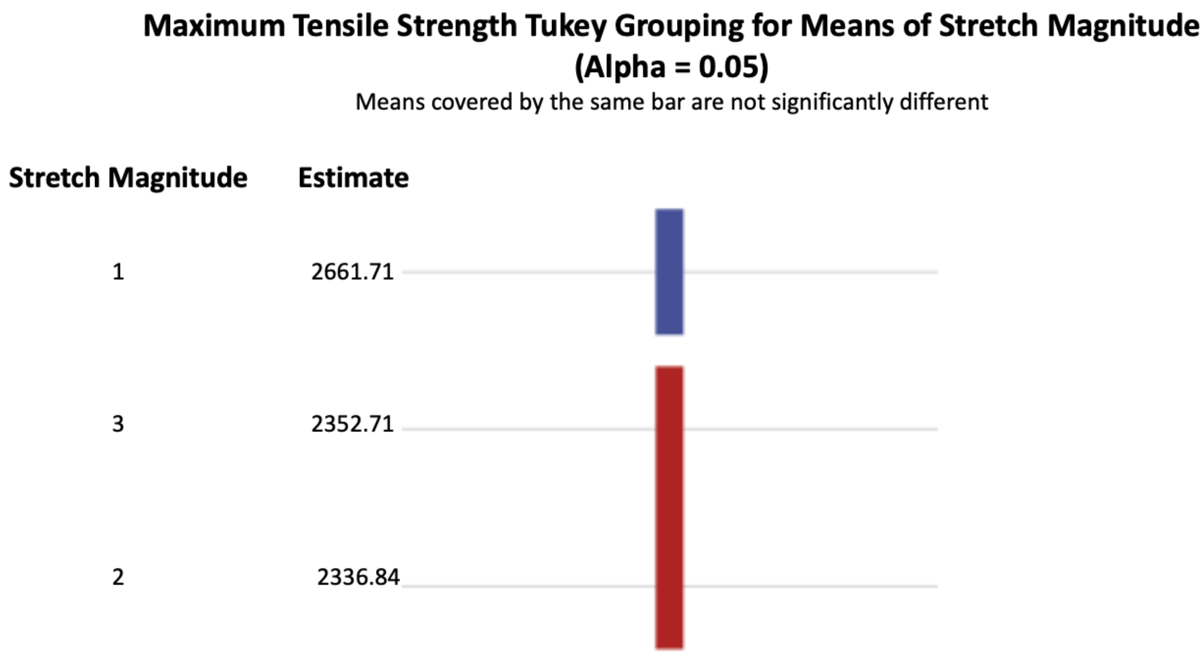


Figure 13. Tukey's Honestly Significant Difference Test for stretch magnitude and mean maximum tensile strength. (1 = unstretched, 2 = small stretch, 3 = large stretch)



CHAPTER 5

DISCUSSION

Orthodontists are faced with the decision to choose between many different bracket systems, bracket sizes, ligature methods, and treatment mechanics. Each of these options have their own advantages and disadvantages, and the orthodontist must decide what works best in their hands. Among these decisions, are the choice between using large or small brackets. Smaller brackets have the advantage of increased inter-bracket distance, making the forces that move teeth lighter and more comfortable for the patient. Smaller brackets are also thought to be more esthetic than their larger counterparts. However, smaller brackets with smaller wing perimeters offer less control of rotational forces and crown tipping than do larger brackets with larger wing perimeters.

While small and large brackets are able to be manufactured with the same prescription for torque, tip, and rotation; the orthodontic archwire must be fully engaged within the bracket slot to fully express the prescription of the bracket clinically. Small and large twin brackets have different perimeters of the wings that elastomeric ligatures must stretch around when securing archwires into the bracket slot. This study hoped to introduce another potential factor in the decision to use small versus large brackets by investigating the maximum tensile strength of elastomeric ligatures tied around one of the smallest (Forestadent Microsprint) and largest (American Orthodontics Master Series) orthodontic twin brackets on the market. This is important because while elastomeric ligatures are the most common way of securing orthodontic archwires into the bracket slots, they have many favorable and unfavorable attributes. Orthodontic elastomers are known to experience 50-70% force decay within 24 hours of stretching. This decay continues at a slower rate for 2-3 weeks, at which point only 30-40% of the original force remains (Baty et al., 1994) This force decay may reduce the ability of elastomeric ligatures to maintain full engagement of the orthodontic archwire into the slot, and also may lead to more failure and tearing of the elastomeric ligatures. In the current study, when comparing groups when only one factor was varied between those two groups, the percent reduction in tensile strength ranged between 6 and 24% with an average of 16% reduction in strength due to artificial saliva exposure. Similarly, for comparing groups when only the stretch was the factor to vary, the small stretch group reduced strength by an average of 12% (5 to 19% range among four comparative groups) and the large stretch group showed an average of 14% (5 to 20% range among 4 comparative groups) reduction in tensile strength. The difference between these results from the current study and those stated by Baty et al. can be explained by inadequate amount of initial stretch to elicit a 70% force decay after 4 weeks, and the use of in-vitro conditions instead of in-vivo conditions.

Overall, the current results indicate similar mean maximum tensile strengths between American Orthodontics and Dentsply Sirona elastomeric ligature ties in all testing conditions. In general, unstretched elastomeric ligature ties showed the highest mean maximum tensile strength compared to stretched ligatures. This pattern held true among most test groups in both dry and artificial saliva conditions.

The findings of a decrease in tensile strength of elastomeric ligatures after 4 weeks in artificial saliva support the results of Ahrari et al. (2010). Artificial saliva reduced the mean maximum tensile strength when compared to dry samples subjected to the same magnitude of stretch. This can be explained by the possible chemical breakdown of the elastomeric material by the salts, as well as plasticization of the polymer by the artificial saliva during the incubation period. The current findings of a decrease in tensile strength after elastomeric ligature ties were stretched to the diameter of a large twin bracket are similar to those of Taloumis et al. (2010). Compared to unstretched elastomeric ligature ties, stretched elastomeric ligature ties in both the small and large stretch magnitudes had a significantly lower mean maximum tensile strength after 4 weeks of incubation. However, there was no statistically significant difference in mean maximum tensile strength between elastomeric ligatures stretched around the small and large brackets used in this study in any of the conditions tested. This was found despite evidence of different degrees of permanent deformation between these groups after the storage period (Figure 3). The permanent deformation observed may be due to a creep process, in which slippage of the polyurethane chains occurred within the ligatures due to the continuous, though, decreasing force that was keeping the ligature secured to the bracket. This process can cause unrecoverable deformation in the elastomeric ligatures, even after the force is removed. The observation of statistically insignificant differences in mean maximum tensile strength between the stretched ligatures, in contrast to the visual differences in the permanent deformation seen in these groups, is similar to the findings of Eliades et al. (2004). In that study, the authors did not observe a difference in tensile strength between as-received orthodontic elastomeric chains and orthodontic elastomeric chains that were stretched approximately 50% of their original length after 3 weeks in air or in-vivo conditions. This suggests that the difference between the wing perimeters of the small and large brackets used in the current study that resulted in approximately a 70% difference in stretch between the elastomeric ligatures secured around them may not have been large enough to elicit a large enough difference in stretch to create a significant difference in mean maximum tensile strength between these groups. Clinically, this means that the security of an archwire within the bracket slot of the small and large brackets used in this study may not be different when elastomeric ligature ties are used.

This study does have limitations to external validity and clinical application in vivo. The first limitation is that only two brands of elastomeric ligature ties were tested. There are various other companies that manufacture different dimensions of elastomeric ligature ties that may be affected differently by stretching. The second limitation is that the elastomeric ligature ties were not used to secure an archwire into the brackets tested, as they normally would be clinically. Rather, the ligatures were tied around a bracket with no wire inserted. This may affect results, in that a greater stretch would be required of the elastomeric ligature if a wire was inserted into the bracket slot, which can increase the loss of tensile force over time. In addition, smaller dimension archwires may require less of a stretch of an elastomeric ligature to be secured into a bracket slot than larger dimension archwires. This may have an effect on the amount of tensile strength lost over time. A third limitation is that the ligatures were tested in artificial saliva, which is not composed of the same enzymes or proteins that human saliva contains. Because of this, this in vitro study may underestimate the magnitude of degradation and strength loss of the elastomeric ligature ties in vivo. The last limitation of the present study is that one operator tied in and removed all ligature ties to reduce variability among examiners. This introduced operator bias in that different operators may insert and remove elastomeric ligature ties in different ways.

Furthermore, this study does elucidate future areas of investigation. Many orthodontists secure archwires into bracket slots using a figure 8, or “butterfly” pattern of elastomeric ligature placement with the belief that it increases the force applied to the wire by the elastomeric ligature, and better secures the archwire into the bracket slot as a result. To the author’s knowledge, the tensile strength of butterfly tie placement has not been investigated in comparison to conventional elastomeric ligature tie placement. Another future investigation could evaluate the maximum tensile strength of elastomeric ligatures tied around brackets with a wire inserted, which may be more clinically applicable. Lastly, an in vivo investigation of maximum tensile strength of elastomeric ligature ties tied around small and large brackets may produce more clinically relevant results.

CHAPTER 6

CONCLUSIONS

In conclusion, there was not a significant difference between American Orthodontics elastomeric ligatures and Dentsply Sirona elastomeric ligatures under any test condition in this study. Incubation in artificial saliva for 4 weeks at $37\pm1^{o}C$ significantly reduced the mean maximum tensile strength of elastomeric ligatures compared to dry ligatures incubated at $37\pm1^{o}C$ in all magnitudes of stretching. The difference in mean maximum tensile strength of elastomeric ligatures stretched over small and large bracket wing perimeters was insignificant, but the mean maximum tensile strength of unstretched elastomeric ligatures was significantly higher than the stretched groups in both dry samples and samples incubated in artificial saliva.

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