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The Effect of Modifications to Intermaxillary Orthodontic Elastics on Force Levels and Degradation Over Time

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Abstract

Introduction: Orthodontic elastics are frequently used in orthodontic treatment but there is little research into how to modify their prescription to improve their performance. The aim of this study was to evaluate potential wear modifications to a standard Class II intermaxillary elastic prescription on force levels and force degradation over time.

Methods: For this in vitro study, Ormco (OR) and American Orthodontic (AO) latex elastics had five modifications made to a standard 1/4”/4.5oz control elastic (Group 1). These included an increase of force level by one unit to 6 or 6.5oz (Group 2); a decrease in lumen size to 3/16” (Group 3); a doubling of the control elastic (Group 4); a 720° twist added between the two ends (Group 5); and an increase in initial stretch length by one tooth (Group 6). Elastics were tested on an elastic stretching apparatus with parameters imitating the use of intermaxillary elastics for the treatment of Class II malocclusions. Intraoral conditions were simulated with a distilled water bath maintained at 37°C and cyclic stretching of 1 stretch/min to mimic oral functioning. Force was assessed at time points 1, 5, 30, 60, 180, 360 and 720 minutes. A Two-way Mixed ANOVA was used to identify statistically significant differences between groups and time points ($p<.05$).

Results: Mean force level values were significantly greater at all time points for Groups 2, 4, and 6 as compared to control Group 1 in both OR ($p<.001$) and AO ($p<.05$) elastics. Group 5 had significantly decreased force levels in OR ($p<.05$) elastics. Groups 3 and 6 had the greatest percentage force degradation over time in both manufacturers. The majority of groups showed significant decreases in mean force levels between each successive time point up to T-60 or T-180 for OR, and up to T-180 or T-360 for AO.

Conclusions: Increasing elastic force by one unit, doubling elastics, and increasing elastic stretch by one tooth showed significant increases in force levels at all time points as compared to the standard control elastic.

Keywords

Orthodontic Elastics, Intraoral Elastics, Intermaxillary Elastics, Class II Elastics, Latex Elastics, Force Degradation

Summary for Lay Audience

Introduction: It is known that orthodontic elastics (or rubber bands) wear out and forces decline over time based on many different variables. However, recommendations on how orthodontists can apply this information when deciding which elastics to prescribe patients is incomplete. The aim of this study was to evaluate five potential changes to a commonly used elastic prescription to correct Class II malocclusions and see how force levels change over time.

Methods: A custom built testing machine was used to stretch the common elastic (Group 1) and the elastics with the five changes. The changes included: the same size elastic but increased force (Group 2); a smaller size elastic with the same force (Group 3); two of the common elastics placed at the same time (Group 4); the common elastic with two full twists (720°) placed between the two ends (Group 5); and stretching the common elastic to include one more tooth (Group 6). Elastics were stretched on the testing machine to the average length patients need to wear elastics with their braces. The machine helped imitate the conditions found in the mouth by having the elastics in water at body temperature and stretching the elastic periodically to mimic mouth movements. The elastics were tested for 12 hours on the machine with comparisons made at intervals of 1, 5, 30, 60, 180, 360, and 720 minutes. Elastics tested were from two different companies to see if differences were consistent between manufacturers. Statistics were used to analyze the differences between groups and between the different time intervals

Results: The changes made to Groups 2, 4, and 6 increased the force levels at all the time intervals and in both companies' elastics. Group 5 had decreased force levels in one of the companies. The forces in groups 3 and 6 decreased the most over time. The biggest changes in elastic decay were seen early on in all groups with elastics wearing out less as time passed.

Conclusions: Increasing the force level of the elastic, doubling the elastic, and increasing the elastic stretch by one tooth increased force values compared to the common elastic, while twisting the elastic decreased force values. Decreasing the size of the elastic or increasing the distance it is stretched caused an increased rate of elastic degradation over time.

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Table of Contents

List of Tables

List of Figures

List of Appendices

List of Abbreviations

OR = Ormco

OR1 = OR 1/4” and 4.5 ounce elastic (Control Elastic)

OR2 = OR 1/4” and 6 ounce elastic (Same Lumen Size, Increased Force Level)

OR3 = OR 3/16” and 4.5 ounce elastic (Lesser Lumen Size, Same Force Level)

OR4 = OR 1/4” and 4.5 ounce X2 (Double the Elastic of the Control)

OR5 = OR 1/4” and 4.5 ounce with 720 degrees twist (Twisted Force Level)

OR6 = OR 1/4” and 4.5 ounce with initial stretch length increased (Add Extra Tooth for Initial Stretch)

AO = American Orthodontics

AO1 = AO 1/4” and 4.5 ounce elastic (Control Elastic)

AO2 = AO 1/4” and 6.5 ounce elastic (Same Lumen Size, Increased Force Level)

AO3 = AO 3/16” and 4.5 ounce elastic (Lesser Lumen Size, Same Force Level)

AO4 = AO 1/4” and 4.5 ounce X2 (Double the Elastic of the Control)

AO5 = AO 1/4” and 4.5 ounce with 720 degrees twist (Twisted Force Level)

AO6 = AO 1/4” and 4.5 ounce with initial stretch length increased (Add Extra Tooth for Initial Stretch)

T-1 = time point 1 minute

T-5 = time point 5 minutes

T-30 = time point 30 minutes

T-60 = time point 60 minutes (1 hour)

T-180 = time point 180 minutes (3 hours)

T-360 = time point 360 minutes (6 hours)

T-720 = time point 720 minutes (12 hours)

A-P = Anterior-posterior

LC = Load Cell

SD = Standard Deviation

oz = ounce

g = grams

mm = millimeters

sec = second

min = minutes

hr = hour

Chapter 1

1 Introduction

The purpose of orthodontic treatment is to create tooth movement that ultimately leads to properly aligned and interdigitated teeth. When done appropriately, functional and esthetic results are produced. Light continuous force levels are recommended during orthodontic tooth movement to promote bone and gingival health. These light force levels allow for cell survival within the periodontal ligament and remodeling of the tooth socket through frontal resorption rather than necrosis and undermining resorption.[1] Anterior-posterior (A-P) movement of teeth can be accomplished in a variety of ways. Some options include intraoral elastics, elastomeric chains, removable appliances, coil springs, functional appliances, and extraoral devices (Figure 1).

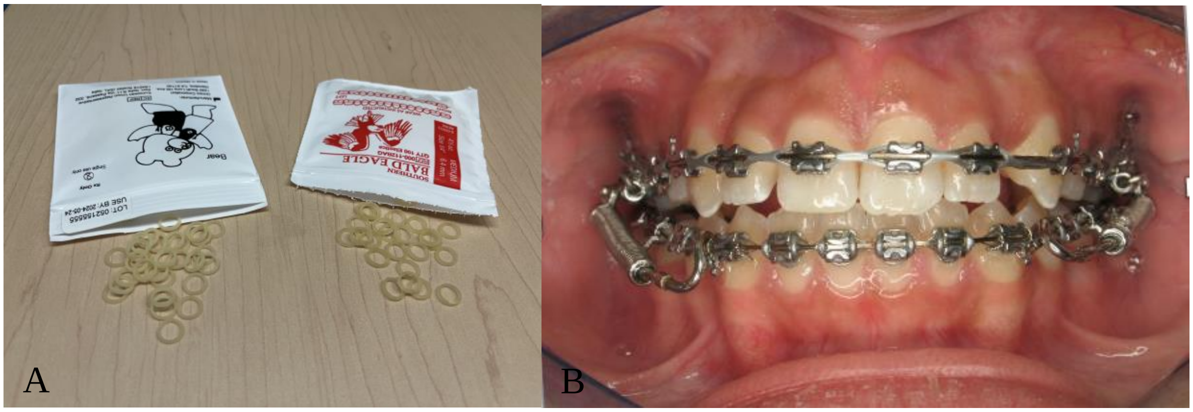

Figure 1: A) Intraoral elastics **B)** Forsus® Fixed Spring Appliance

Intraoral elastics have been used in orthodontics since the 1890s. There is some debate as to who first started using them. Most practitioners of that era give Henry Baker credit when he introduced them as what he termed “Baker anchorage” in 1893. Calvin Case is also given credit by some as he claimed to have started using intraoral elastics earlier and allegedly reported on it at the Chicago Dental Society in 1890.[2,3] The low cost and versatile use of intraoral elastics have helped them become a mainstay in orthodontic treatment. They are used in a variety of ways, including moving Class II and Class III A-P relationships to Class I occlusions, correcting crossbites, midline discrepancies, closing spaces, and settling the occlusion.

A potential disadvantage to intraoral elastics is that patient compliance is required. The orthodontist provides the elastics and prescription for elastic use and the patient is responsible for elastic placement and the changing of elastics. Al-Moghrabi et al[4,5] report that there is consistent deficiency in patient compliance with all types of removable orthodontic appliances and adjuncts and that patients routinely overestimate their extent of compliance. They have found that patients are more likely to be compliant when they are younger and/or in the earlier stages of treatment. Leone et al[6] recently reported on a 3.7 times greater Class II correction in an experimental group that received text message reminders to wear their elastics.

1.1 Orthodontic Forces

Creation of tooth movement is determined by the amount of force placed and the duration of that force on the tooth or teeth. When force is applied over time, it stimulates remodeling of the alveolar bone. This remolding can occur in several ways depending on the amount of force applied. The periodontal ligament is compressed by force, reducing its width, and causing vascular changes within it. If the force is heavy, pain will develop, and necrosis of the cells occurs through undermining resorption. Hyalinization is a term often used for areas of tissue that lack cellular elements. Lighter forces that are compatible with cellular survival do not lead to pain and cause frontal resorption within the tooth socket. This remodeling allows tooth movement to occur.[1,7]

In 1957 Reitan[8] described a considerable variation seen in normal tissue, depending on age. Adults contain fewer cells in the periodontal space, have thicker periodontal bundle fibers, and less osteoblasts than adolescents. Other variables that can effect tooth movement include patient growth, individual anatomy, fibrous tissue variability, bone density, root length and number, type of tooth movement required, abnormalities such as hypercementosis, and previous trauma or ankylosis.[8–10] Hixon et al[11] considered the high variability of the surface area of roots to be clinically significant for tooth movement as well.

The trend in orthodontics has moved over time to the use of light continuous forces to create tooth movement. With these forces, tooth movement is achieved while limiting the amount of pain. Blood flow also continues in the area which permits frontal resorption and limits necrosis. This allows osteoclasts and osteoblasts to survive and help with alveolar bone remodeling. Andreasen[12] explained that the definition of a “light” force is somewhat ambiguous and he noted that no one, including Reitan had defined the term. He continued by offering the range of 50-200g that Reitan used in his intraoral histological studies of tooth movement as a reference point for intermaxillary elastic force levels.

Manufacturers recommend intermaxillary elastics ideally be stretched three times the lumen width and they have the corresponding ounces and grams of force to be expected listed for reference.[13] In 1977, Bales et al[14] found that the force levels were typically higher than reported by the manufacturers. When using Class II elastics, Proffit[1] recommends 250g per side with a rectangular wire and half that amount, 125g, when using a lighter round wire. Bishara[7] recommends approximately 300g per side for interarch movement. Langlade[13] calculated optimum tooth movement force levels based on Ricketts root resorptive surface area model of 150g of force per cm^2. This amounted to 318g per side when moving one arch relative to the other.

Oesterle et al[15] studied clinical orthodontists recommendations for intermaxillary elastic use in Class II patients and found large variations in prescribed forces. For rectangular wires they reported a range of 132-464g with a mean of 277 ± 89g and a median of 256g. Round wires had a range of 59-284g with a mean of 183 ± 59g and a median of 177g. All recommendations fell within one standard deviation of Dr. Proffit’s recommendations. Ren et al[16] performed a systematic literature review in 2003 and found that no evidence based optimal force level in orthodontics could be found from the available literature.

1.2 Class II Orthodontic Treatment

The prevalence of Class II malocclusions varies substantially depending upon the local population. Alhammadi et al[17] performed a systematic review on the global distribution of malocclusion traits. The mean distribution of Class II malocclusions in the permanent dentition are 19.6% on a global scale. This increases to 23% in the mixed dentition. When looking at North and South America only, these means are 15.3% and 27.2% respectively. Prevalence by race differs, Africans are lowest with 6.8% and 5.1% while Caucasians report the highest-Class II malocclusion frequencies at 22.9% and 25.9% respectively.

In 1938 Goldstein and Myer[18] published completed Class II cases which followed the treatment methods described by Drs. Angle, Brodie, and Wright with the use of intermaxillary elastics. Today, intermaxillary elastic use for Class II cases is standard (Figure 2) along with other previously mentioned options. Janson et al[19] performed a systematic review in 2013 and concluded that on a long term basis, there were no significant differences between the effects of Class II elastics and other removable or fixed functional appliances when treating Class II malocclusions. Nelson et al[20] explained their findings from lateral cephalograms, with clear differences when comparing elastics and the Herbst functional appliance in the short term, but the differences were non-sustained in the long term.

Figure 2: Class II patient treated with orthodontic elastics for A-P correction at Western University Graduate Orthodontic Clinic. **A)** Before treatment **B)** Near end of treatment

In 1959, Wein reported his findings on the effects of Class II elastics on cephalometric measurements. On average, SNA decreased slightly, SNB increased slightly, ANB decreased, and the maxillary incisor tipped palatally, while the mandibular incisor tipped labially.[12] More recently, Reddy et al[21] reported a significant decrease in the ANB angle and in Wits with minimal mandibular growth in Class II growing children. They also found a significant increase in the anterior and posterior facial heights and the ramal height. These findings align with our knowledge that there are vertical and horizontal forces involved in the use of Class II intermaxillary orthodontic elastics.[13]

The effects of Class II elastics should be considered with the individual case in mind before prescribing the elastics. These effects include proclination and intrusion of the mandibular incisors; palatal tipping, retrusion, and extrusion of the maxillary incisors; mesialization and extrusion of the mandibular molars; and clockwise rotation of the occlusal and mandibular planes. These effects are mainly dentoalveolar.[19,21–23] Janson et al[19] further explained that the occlusal plane angle has a tendency to return to its original position later.

Stanley[22] found that there is no statistical differences in force systems generated between using a light (0.014-in Nitinol) archwire or a heavy (0.019 x 0.025-in Stainless Steel) archwire with light elastics (2oz). Since patient compliance is best when the patient is young and/or at the beginning of treatment, Stanley states that early light elastic treatment can be rationalized. The use of a heavy archwire statistically reduced the extrusive forces found on the maxillary canines and mandibular molars when using heavier elastics (4.5oz). This should be considered if the treatment plan includes limiting extrusion of teeth.

1.3 Composition of Intraoral Elastics

The effectiveness of natural rubber had always been limited by its unfavorable temperature behavior and water absorption properties. In 1839, Charles Goodyear was the first to heat sulfur and rubber mixtures, now known as vulcanization. This greatly increased the possible uses of natural rubber. Although, natural rubber elastic use in orthodontics was first tried and reported in the 1890s, it wasn’t until the 1960s that elastic use became very prevalent. The importance of rubber became obvious during World War I, and after the war, efforts to produce synthetic rubber were continued. In the 1920s, scientists developed synthetic rubber polymers from petrochemicals.[24–26]

As our knowledge has increased, manufacturers have added additional components such as antioxidants and antiozonants to retard limitations and extend the shelf life of elastics. Chemical analysis of latex shows 30-35% pure rubber, 60-65% water, and small amounts of other materials such as resins, proteins, sugar, and mineral matter. Latex is processed into crude rubber as soon as possible after being tapped to avoid spoiling. Today, both natural rubber and synthetic elastomers are widely used in orthodontics. They are found in the form of intermaxillary elastics, elastic thread, power chain, and elastomeric ligatures.[24–26]

Intermaxillary elastics were fabricated primarily from natural latex rubber until the early 1990s when a non-latex or synthetic option began to be marketed for patients with latex allergies or sensitivities.[27,28] Options are varied for orthodontists with many manufacturers, sizes and force levels available on the market. Manufacturers don't share their proprietary methods of fabricating their orthodontic elastics but tend to use words such as, "high-quality surgical latex" and "exacting dimensions" in their promotional materials and product catalogs. Long latex or non-latex tubes are cut to desired thickness with sharp blades covered in PAM® Cooking Spray to prevent sticking. Corn starch is used upon packaging to prevent sticking of elastics inside the pouches.

Orthodontic manufacturers alter the variables of size and force to fabricate a spectrum of intraoral and extraoral elastics. These elastics are used by orthodontists to meet the individual force level needs to correct their patients' malocclusions. The variable of size is established off the initial lumen length and standard sizes range from 1/8" to 3/4" with the most commonly used sizes ranging from 3/16" to 5/16". The variable of force is normally reported in ounces. Standard force levels range from 2 to 14oz, including extraoral elastics. The most commonly used force levels intraorally range from 3 to 6oz. Intraoral and extraoral options are available for use with different appliances or devices.

1.4 Elastomer Degradation

The word elastomer is used by chemists to describe any substance that stretches easily to many times its length and returns to its original shape when released, such as natural and synthetic rubbers.[26] Kanchana and Godfrey[29] used three different sizes of latex elastics from four different manufacturers and stretched them varying distances, including the recommended three times the lumen length. They measured force levels and found them to be higher, across all sizes and manufacturers, than the reported expected values at three times the lumen length. They also stated that as expected, force levels increased as the lumen was stretched further and decreased as the lumen length decreased. Initial force levels varied substantially by manufacturer. A range of initial force levels that were 9.5% to 41.9% higher than their standard force index were found. Degradation of the elastics varied significantly between different sizes and forces. Generally, they saw a 70% force retention rate over one hour and 64% force retention after three days.

Russell et al[30] tested elastics from the manufacturers GAC and Masel at two times and three times the lumen length. Both manufacturers reported an expected initial force level of 113g with 4oz and 1/4” elastics. GAC results were 74.9g at two times the lumen length and 140.7g at three times the lumen length. Masel results were similar at 74.3g when two times the lumen length and 134.4g at three times the lumen length. These findings confirm those of Kanchana and Godfrey[29] in both increased expected initial force level values and the correlation of increased forces with increased stretch length and vice versa. Force degradation was less than Kanchana and Godfrey’s[29] findings with 82-83% of force levels retained in the first hour and 75% retained after 24 hours. Russell et al[30] concluded that the mechanical properties of the elastics studied were substantially varied and that few general conclusions could be drawn and applied clinically.

Kershey et al[31] further confirmed the correlation of increased forces with increased stretch length and vice versa. They tested American Orthodontics latex elastics in cyclical stretching conditions and found a lower mean initial force level of 122.2g when the expected standard force index was 127.5g. Kershey decreased the first time point to 30min and concluded that the majority of force degradation was occurring within those first 30min. They found 81% of initial force remained at 30min and 75% remained after 24 hours.

Tran[32] tested Ormco 1/4”/3.5oz latex elastics which have an expected standard force index of 100g. An initial mean force level of 114g was recorded. There was 85% remaining of initial force levels after both one hour and 24 hours. Fernandes et al[33,34] tested latex elastics in a static tensile state using three different sizes and three different manufacturers. They concluded that most force extension relaxation occurred within the first three hours regardless of size and manufacturer.

Yang et al[35] analyzed six distinctive sizes and two different force levels of 3M Unitek latex elastics in vitro and in vivo. The results indicated that force degradation is greater in vivo than in the in vitro wet or dry environments. They noted that the larger the lumen size and/or the smaller the force value, the slower the force decayed. There are many potential factors that can cause degradation to elastomers over time. The current literature gives us further insight on manufacturers and degradation, latex and non-latex elastomers, in vivo and in vitro studies, the effects of cyclic stretching, the role of temperature, the role of the surrounding environment, and the effects of pigmentation.

1.4.1 Degradation Effects According to Manufacturer

More than 15 different manufacturers of orthodontic elastics are found in the current literature. Manufacturing methods and materials are typically proprietary and are not shared with others. This of course causes variation in performance between manufacturer's orthodontic elastics. Poor quality control and production standards within a manufacturing company can lead to variation within the same brand of elastics.

Kanchana and Godfrey[29] tested four manufacturers (Unitek, Ormco, Tomy, and Dentaurum) and reported significant differences in force degradation characteristics between extensions, force magnitudes, and manufacturers. They also reported that generally, force degradation was around 30% in the first hour, up mildly to 32.6% during the first 24 hours, and at 36.2% after three days. Wilson[36] reported force degradation after one hour at 25% for OR, 21% for AO, and 23% for Auradonics elastics. At 24 hours he found 33% force loss for OR and Auradonics and 30% for AO.

1.4.2 Degradation of Latex vs Non-Latex Elastics

Today latex and non-latex orthodontic elastics are available to orthodontic practitioners and patients. Many studies have compared these two types of elastics and their degradation levels over time. The inclusion of other potential factors of degradation are varied throughout these studies. Non-latex elastics have been shown by most studies in the literature to degrade more quickly and for longer periods of time when compared to their latex counterparts.[27,28,31,32,36–41] There are a few studies with contrary or mixed results. Ardani et al[42] found latex elastics to degrade more readily than non-latex up to 24 hours with no significant difference in elastic degradation between 24 and 48 hours.

Russell et al[30] tested two different orthodontic elastic manufacturer's (GAC and Masel) and found that GAC latex elastics retained larger force levels than their non-latex counterpart while Masel non-latex elastics were better at retaining their load over their latex counterpart. Pithon[43] tested distended latex and non-latex elastics attached to thermoplastic plates placed in the oral cavity. Evaluations at initial, 12 hours, and 24 hours showed 1/8” latex elastics retaining higher force levels throughout while 1/4” and 5/16” non-latex elastics maintained higher forces levels at 12 hours but showed no significant difference by 24 hours.

Due to most studies showing more favorable outcomes with latex elastics, they remain widely used today despite a minor part of the population having sensitivity or allergies to the latex. In fact, non-latex elastics are seldom used today, except for those patients that require them due to sensitivity or allergy responses. Many manufacturers have stopped producing non-latex elastics due to the lack of demand and the undesirable degradation properties. Until a better alternative is presented, latex elastics will continue to be a mainstay of orthodontic treatment.

1.4.3 Degradation of Elastics In Vivo vs In Vitro

The available literature for degradation of elastics includes both in vivo and in vitro studies. Clinical application of orthodontic elastic research is the goal so it is important to understand that in vivo studies provide the natural environment but can also make it difficult to isolate other potential degradation factors to study. In vitro studies can help with this concern and add important information to the knowledge available. Yang et al[35] recently compared latex elastic degradation of in vivo studies compared to in vitro studies in air and in artificial saliva. Results showed greater degradation of elastics during the in vivo study.

Wang et al[44] also compared elastic degradation between in vivo and in vitro studies. Their two in vivo groups included intermaxillary and intramaxillary elastic wear. The in vitro part of the study had one group in artificial saliva and the other group in dry air. They found the greatest degradation of force in the intermaxillary group, followed by intramaxillary group, artificial saliva, and finally dry air.

The in vivo groups were further divided based on start times to see if daytime compared to nighttime wear would impact degradation of forces. They concluded that for intermaxillary elastic wear, those who started wearing elastics in the morning saw more obvious force degradation then those who began wearing them at night. They described this phenomenon as a primary effect due to mechanical stretching and listed oral temperature, salivary situation, enzymes, and acidic and alkaline stimuli from various foods as other influential factors. The intramaxillary groups showed no significant differences based on start times.

Notaroberto et al[39] used an in vivo split mouth design study and determined that latex elastics degrade less than non-latex elastics in vivo. This correlates well with most in vitro study results. Qodcieh et al[45] tested medium and heavy 3/16” Class II elastics in vivo. They concluded that 50% force degradation occurs within four to five hours followed by continuous and gradual force degradation. Pithon et al[43] also used an in vivo study to determine that intermaxillary elastics show significant and progressive reduction in force levels over time.

1.4.4 Degradation Effects of Cyclic Stretching

Intermaxillary elastics are not in a static situation when prescribed for use inside a patient’s mouth. They are susceptible to stretching as a patient goes about their normal daily functions such as speaking, yawning, and even eating in some compliant patients. This cyclic stretching of elastics has been shown to increase degradation of orthodontic elastics, especially in the first hour.[28,31,40,46,47] Lin et al[48] found that as the amount of cyclic stretching accelerates, there is an increase in elastic degradation and probability of breakage.

Qodcieh et al[45] report that the amount of anterior mouth opening had a significant effect on force degradation of elastics. They also found that force decay of elastics was correlated with the lateral distance from the maxillary canine to the mandibular first molar. Mansour[49] used thirty non-extraction, Class I models to find the mean distances from the maxillary canine to the mandibular first and second molars, which are common Class II elastic patterns. These mean distances are 22.3mm and 38.7mm respectively. Kersey et al[31] found data from a computer model of the masticatory system created by Peck et al[50]. They used this data to determine that a maximal opening of 50mm would create a distance change between the maxillary canine to mandibular first molar of 24.7mm.

1.4.5 Degradation Effects of Temperature

Temperature has the potential to be a factor of degradation of elastics initially and over time. Gonzaga et al[51] studied the impact of temperature and humidity on initial force levels of elastics when first received and after one year of storage. They compared room temperature storage to refrigerated storage and closed or opened the bags to allow for humidity exposure. They concluded that temperature and humidity had no impact on initial force levels after one year of storage.

Paige et al[52] studied the direct effect of temperature on elastics by incubating them in water baths at 4°, 21°, 37°, and 50° Celsius for 15min. Their results show that as temperature increases a decrease in sustained force levels is seen. Paige[53] further tested cyclic temperature changes by immersing elastics in two different distilled water baths of varied temperatures for 20 cycles at three seconds per cycle. The temperatures selected loosely correlated with different beverages typically consumed. He found that latex elastics lose the most force when cycled between hot and cold temperatures.

1.4.6 Degradation Effects of the Environment

The environment an orthodontic elastic is placed in can have a significant effect on force degradation. Kanchana and Godfrey[29] noted that force degradation was more pronounced in a wet environment compared to a dry one. Lopez et al[41] found significantly more force degradation in the wet environment with both latex and non-latex elastics. Yang et al[35] compared the oral environment to both wet and dry conditions in vitro. Their results showed highest elastic degradation in the oral cavity followed by a wet environment and the least amount of elastic degradation in a dry environment.

The degradation effects of the chemical nature of different beverages has been reported by Leao Filho et al[54]. They examined the impact of Coca-Cola™, beer, orange juice, red wine, and coffee on intermaxillary elastic degradation and found no influence. Pithon et al[55] also studied beer and wine with additional alcoholic beverages including whiskey, brandy, vodka, and rum. These beverages were studied in relation to elastic chain. They had no influence on the decline of force levels. Beattie and Monaghan[56] tested food products including Reese's™ Puffs cereal, Beefaroni™, chicken fried rice, and Milky Way™ by crushing them into orange juice, Coca-Cola™, or milk and immersing the elastics in the different baths. No differences were found between the control and the food baths.

Shilaja et al[57] studied the effects of pH on elastic degradation. They used elastics from three manufacturers at pH levels of 5, 6, and 7.5. The elastics were stretched at 225%, 300%, and 450%. No significant influence was noted by pH on elastic degradation over time. Ajami et al[58] set their pH levels at 5 and 7. They included a third and fourth group of latex elastics that had an intermittent pH drop to 4 from pH levels of 5 and 7 respectively. No significant correlation was seen between the intermittent pH drop and elastic force degradation except at 36 hours during their 48 hour study.

1.4.7 Degradation Effects of Pigmentation

Historically intraoral elastics were a natural color but over time pigmentation began to be added to create colored elastics as an additional option. Most intraoral elastics used today are still natural color without pigmentation, but colored options exist and are used in some orthodontic offices. The process of coloration is privately held by manufacturers, and much of the process is unknown to the public. We do know that colored polymer pellets are added as a coating rather than incorporating the color throughout the elastic. Multiple colors are found in the elastic pouches.

Ardani et al[42] included some colored intraoral elastics in their study of latex vs. non-latex force degradation study but nothing was mentioned about them in the results or conclusion sections. Wilson[36] specifically studied the effect of pigmentation on both latex and non-latex elastics. He found that green latex elastics generally showed the lowest amount of force remaining after 24 hours. This included all three manufacturers studied, Ormco, American Orthodontics, and Auradonics. The pink colored elastics for American Orthodontics and Auradonics showed higher forces than the rest of the colored latex elastics at all time points. Overall, the colored latex elastics generally had lower force values than the natural latex elastics.

Wilson compared his results to the available graphs and charts from the Ardani et al research on colored latex elastics, and reported consistent observations on these specific findings between the two studies.[36,42] Wilson suggested that different pigmentation may decrease force levels in latex elastics and may increase them in non-latex elastics. He concluded that elastic pigmentation could affect force levels and decay over time but that these results aren't shown consistently across manufacturers, elastic composition, or color. Dos Santos et al[59,60] looked at the cytotoxicity of colored intraoral elastics. They found that Morelli and Uniden elastics, both Brazilian companies, were highly cytotoxic regardless of color while TP orthodontics natural latex was not. The research in this area is limited to their two studies.

1.5 Methodology for In Vitro Studies on Elastic Performance

The measuring of force levels in previous studies has been done in several different ways. Most methods required that the elastic was removed and tested on a force measuring device, then transferred back to their testing apparatus afterwards to continue their protocol until the next force level measuring time point.[27,29,30,32,33,35,37–39,41–45,49,53,54,57,58,61,62] The most commonly used force measuring device was a Universal Testing Machine.[27,29,30,32,34,35,39,41,43,53,54,57,61] These testing machines are used for laboratory tests of different materials and are made by many different manufacturers. Hand held devices such as force gauges, typically mounted to test stands, were also used by several studies to test their force levels.[37,38,42,44,45,49,58,62] The third method used to test force levels after removing the elastic was through an Instron Testing Machine.[29,30,32,53] These machines are considered the gold standard in force measurements when doing materials testing.

A few studies used a different technique that eliminated the need to remove the elastic from the testing apparatus and replace it again. They used force strain gauges that were built into the testing apparatus to allow direct measurements to be taken.[28,36,48] This was done using binocular beam load cells with fixed hooks at one end of the stretched elastic and a connection to a computer program to collect and process the force level readings. The range of maximum force level reading capacity varied in these tests from 200g (2N)[44] on the low end to as high as 20,000g (200N)[61] on the other end.

In vivo studies[35,39,43–45] already have the oral cavity environment as part of the study. In vitro studies often attempt to create a similar environment to increase clinical applicability of their findings. Most studies attempted this by focusing on creating a wet environment around a normal body temperature of 37°C.[14,27–30,32,34,35,41,42,44,48,53,57,58,61,62] The wet environment was accomplished a couple of different ways. Some studies used distilled water[14,28–30,34,36,41] while others utilized artificial saliva.[27,32,35,37,42,44,48,57,58,61,62] Most studies stretched elastics statically between two points and didn't simulate movement of the mouth during function. However, a few studies did incorporate cyclic stretching to better mimic oral function during elastic wear.[28,31,36,40,47,48]

1.6 Problem Statement

Intraoral orthodontic elastic use was introduced over 100 years ago, and for approximately the last 60 years has been very prevalent within the profession. Research has been performed to better understand the degradation of elastic material through variables such as material composition, cyclic stretching, temperature, pH levels, dry and wet environments, beverage exposure, pigmentation, and manufacturers. Force level recommendations from manufacturers, experts, and professionals within the orthodontic field are reported in the literature. However, there is still a lack of information on applying this evidence in the clinical setting when making decisions on altering force levels to produce desired clinical results.

1.7 Purpose

Individual variation in tooth movement can cause an inadequate response to commonly used intermaxillary elastics. The orthodontist must adjust their elastic prescription to alter force levels in such a way that the desired tooth movement can be achieved to produce a successful outcome. The purpose of this in vitro study was to assess a variety of possible modifications to a standard elastic prescription to correct the bite in Class II orthodontic treatment and to determine which modification would lead to more optimal force levels and degradation characteristics. It is anticipated that this information may help orthodontists make clinical modifications to their prescribed elastic wear patterns, thereby increasing the chance that a patient will have a positive response and lead to the creation of the desired tooth movement.

A commonly utilized standard latex elastic prescription for Class II bite correction was utilized as a control (1/4"/4.5oz, attached from the upper canines to the lower first molars) and its force levels and degradation over time was compared to the following elastic wear modifications:

A. Increasing the force level of the elastic
B. Decreasing the lumen size of the elastic
C. Applying two elastics instead of one
D. Adding twist to the elastic
E. Increasing the number of teeth the elastic is being stretched

1.8 Hypothesis

It is hypothesized that significant increases to force levels will be seen in all the proposed modifications to the elastic prescription, with variations in this increase depending on the modification. There will also be an increase in force degradation over time in those modifications that overstretch the elastic considerably past its elastic limit.

Chapter 2

2 Materials and Methods

2.1 In Vitro Testing Conditions

After a review of the literature, the parameters of this in vitro study were selected to simulate bite correction with intermaxillary elastics for a Class II malocclusion. Latex elastics were used due to the overall preference and widespread use of these elastics in orthodontics. Cyclic stretching was set to one stretch per minute with a cycle speed of one second throughout the data collection. No data was found on speed for mouth opening and so the one stretch per minute and the one second cycle speed was taken from previous studies.[28,36] Temperature was set and maintained at or near the temperature of the oral cavity (37°C). To better replicate intraoral conditions, a wet environment was employed during data collection using a distilled water bath. The testing duration was set at 12 hours, as one set of intermaxillary elastics are rarely worn any longer than this, and because the literature shows very little force changes from 12-24 hours or longer.

The length of initial stretch placed on the elastic at insertion was set at 23.8mm. This length was chosen to simulate a mild Class II patient wearing intermaxillary elastics from the maxillary canine to mandibular first molar. Mansour[49] found this mean distance to be 22.3mm for Class I patients. Therefore, 1.5mm was added to the length of the initial stretch to create a mild Class II case to justify intermaxillary elastic use. One modification for this experiment was to simulate adding an extra tooth (ie. extending elastic to the lower second molar). Mansour reported 38.7mm for Class II elastics going to the second molar. For this experiment we used 38.1mm, the maximum our machine would allow, but well within an acceptable range for this scenario. The cyclic stretching length chosen was 25mm. Kersey et al[31] used data created by Peck et al[50] to determine that a maximal mouth opening of 50mm would create 24.7mm between the maxillary canine and mandibular first molar, which was rounded up to 25mm for testing.

2.2 Intraoral Elastics

The control elastic consisted of a 1/4"/4.5oz intraoral latex elastic. Mansour[49] concluded that 1/4” elastics are sufficient to cover the range of force levels for orthodontic treatment. The tested elastics and their prescription modifications are as follow:

Group 1. **Control:** 1/4” diameter, 4.5 ounce force (control)
Group 2. **Increased Force:** 1/4” diameter, 6 or 6.5 ounce force (depending on manufacturer)
Group 3. **Decreased Diameter:** 3/16” diameter, 4.5 ounce force
Group 4. **Double Elastic:** 1/4” diameter, 4.5 ounce force, double elastic (two instead of one)
Group 5. **Twisted Elastic:** 1/4” diameter, 4.5 ounce force, 720-degree twist (placed between ends of elastic)
Group 6. **Increased Stretch:** 1/4” diameter, 4.5 ounce force, stretched an additional tooth (to simulate extension to second molar)

Orthodontic elastics from two different manufacturers were tested to confirm that differences between the control elastic and its modifications were consistent across companies. The elastics tested were manufactured by two leading orthodontic manufacturers, Ormco (OR) (Orange California, USA) and American Orthodontics (AO) (Sheboygan Wisc, USA). The tested elastic groups and their modifications by manufacturer are listed in Table 1 (OR) and Table 2 (AO):

Ormco Elastic Groups	
OR1:	**1/4” diameter, 4.5 ounce force**
OR2:	**1/4” diameter, 6 ounce force**
OR3:	**3/16” diameter, 4.5 ounce force**
OR4:	**1/4” diameter, 4.5 ounce force, double elastic**
OR5:	**1/4” diameter, 4.5 ounce force, 720-degree twist**
OR6:	**1/4” diameter, 4.5 ounce force, stretched an additional tooth**

Table 1: Ormco Elastic Groups Tested

American Orthodontics Elastic Groups	
AO1:	**1/4” diameter, 4.5 ounce force**
AO2:	**1/4” diameter, 6.5 ounce force**
AO3:	**3/16” diameter, 4.5 ounce force**
AO4:	**1/4” diameter, 4.5 ounce force, double elastic**
AO5:	**1/4” diameter, 4.5 ounce force, 720-degree twist**
AO6:	**1/4” diameter, 4.5 ounce force, stretched an additional tooth**

Table 2: American Orthodontics Elastic Groups Tested

Two different lots were used for all elastics tested to account for any possible manufacturing anomalies. Elastics tested for OR had expiration dates 22-31 months away and AO elastics expired 30-32 months after the experiment began. All elastics were kept in the same state they were received, inside their packaging with the plastic seal left in place, until testing began. See Table 3 for the elastics manufacturers, lot numbers, and expiry dates.

Manufacturer	**Elastic Lumen Size**	**Elastic Force (oz)**	**Lot Number Assigned**	**Lot Number**	**Expiration Date**
Ormco (OR)	1/4”	4.5	1	052155555	05-24-2024
	1/4”	4.5	2	092074010	09-15-2023
	1/4”	6	1	06215636N	06-09-2024
	1/4”	6	2	092069497	09-11-2023
	3/16”	4.5	1	06211258N	06-08-2024
	3/16”	4.5	2	092074005	09-15-2023
American Orthodontics (AO)	1/4”	4.5	1	O92136	10-21-2024
	1/4”	4.5	2	O84034	10-07-2024
	1/4”	6.5	1	P01302	11-04-2024
	1/4”	6.5	2	O89189	10-14-2024
	3/16”	4.5	1	O92131	10-21-2024
	3/16”	4.5	2	O79425	09-30-2024

Table 3: Elastic information for study

2.3 Testing Apparatus

Wilson[36] fabricated an orthodontic elastic stretching apparatus. This apparatus is made of rigid aluminum with custom housing for load cells that are attached to one side of each set of the elastic hooks. The other set of hooks are attached to a stepper motor and linear slide rail which provides automated cyclic stretching of the elastics. The hooks are made of stainless steel and are 2mm thick each. They are separated by an additional 1mm which gives an initial separation distance of 5mm. A water tank is located below the hooks and contains a heating element to help control the temperature within 0.2°C of the desired result (Figure 3).

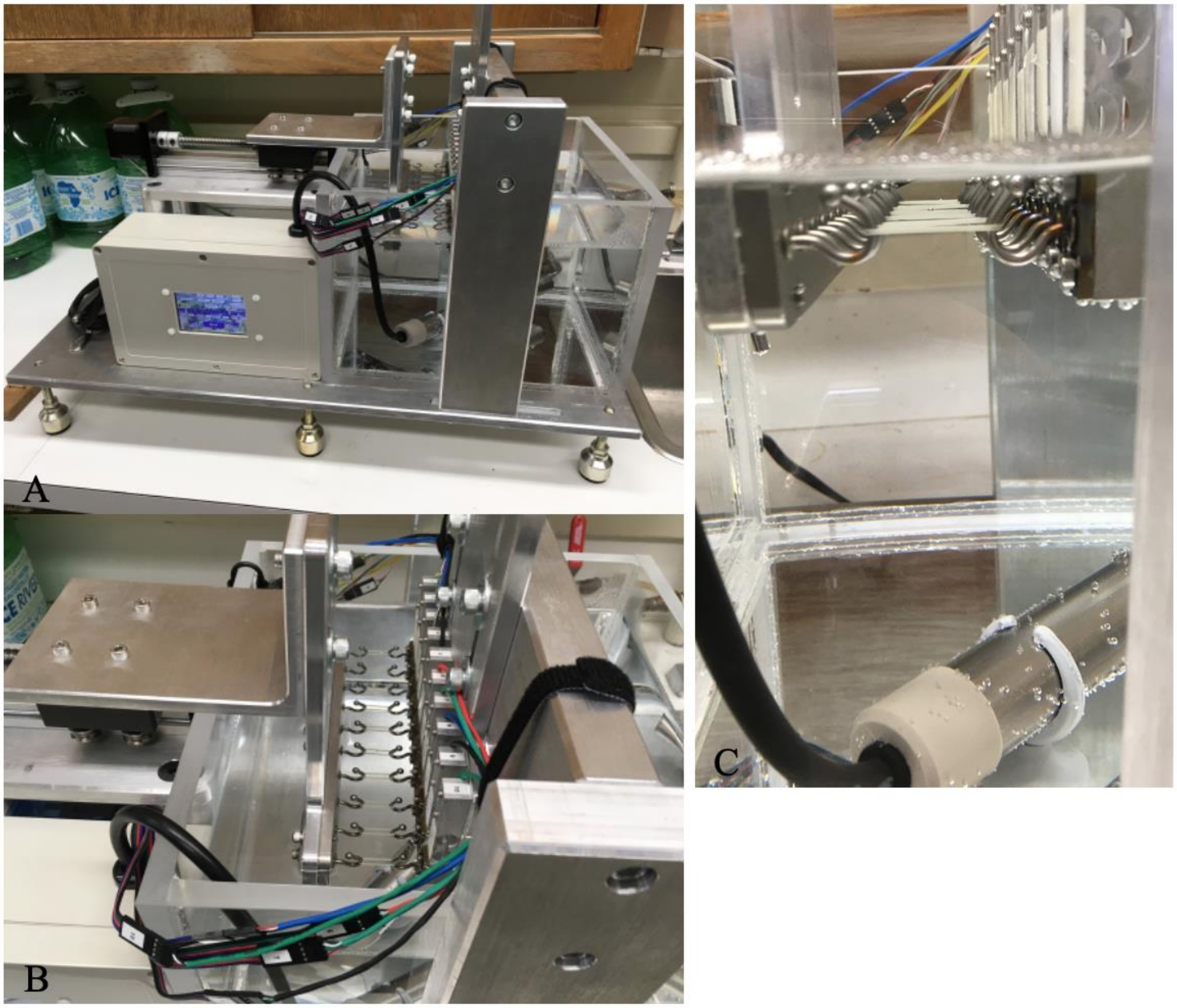

Figure 3: Testing apparatus. **A)** Rigid aluminum framework, stepper motor, and linear slide rail **B)** labeled load cells attached to hooks on right side **C)** elastics at initial stretch, and heating element located below

The apparatus has a 3.5” Color Touch Screen HMI TFT Enhanced Nextion© NX4832K035 LCD display (Figure 4). This display is used to select available options such as desired water temperature (°C), load cell read time (min), cycle stretching time (min), elastic manufacturer (varied), elastic size (in), manufacturer elastic force value (oz), material type (Latex or Non-Latex), elastic color (natural) and desired stretching distance (mm). The touch screen display is attached to the electrical component that controls the apparatus. It is a Keystudio© Mega 2560 R3 (ATmega2560) Arduino “like” microcontroller processor. The processor controls all aspects of the monitoring, processing, data collection, and function of the apparatus.[36]

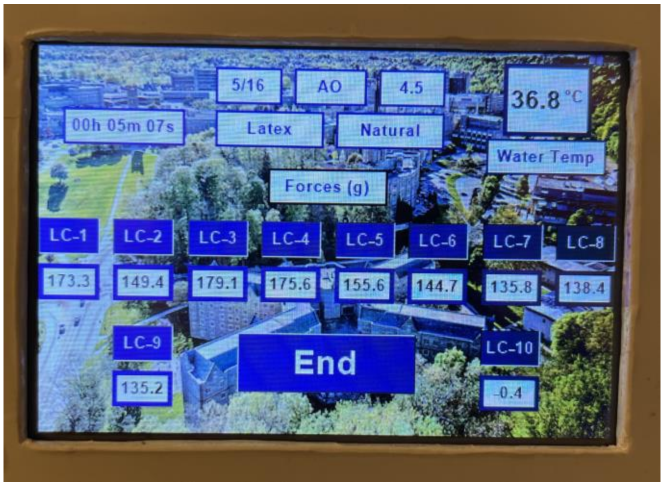

Figure 4: 3.5” Color Touch Screen LCD display

Custom software was created for both the Keystudio© microcontroller and the Nextion© display. This was done using the open-source software packages from Arduino© and Nextion©. All electrical components were soldered to a custom printed circuit board for better stability and reliability of electrical signal transmission. Verification was performed after fabrication of the apparatus. Distance measurements were verified using digital calipers at three different points. The first was the pre-starting distance found from the inside of one hook to the inside of the other hook. The second distance was the starting distance at the initial stretch of the elastic, and the third was the final stretching distance which simulates mouth opening. Measurements with the digital calipers were taken in 0.1mm increments and adjustments were made through the custom software until the desired distances were re-verified four to five times for accuracy and reproducibility.

Force readings of the new apparatus were validated using a Universal Instron Machine (Instron Model #3345; Norwood MA, USA) with a 10 N load cell. Ten 1/4” elastics were placed on the apparatus and pre-stretched to three times their lumen diameter (19.10mm). Elastics were then transferred to a jig to hold their stretched distances and ensure no elastic relaxation would occur between measurements. Elastics were placed on the Instron and force values were measured. To duplicate the planned testing conditions, the elastics were subsequently stretched an additional 25mm at a frequency of once per minute for up to 24 hours for the remaining time points. Elastics were removed and tested on the Instron at time points pre-stretch, 1 minute, 5 minutes, 1 hour, and 24 hours.[36]

The data was validated using SPSS version 24.0 (SPSS, Inc., Chicago, IL, USA). Mean and standard deviations were calculated for both machines at every time point. Normality and a lack of outliers was confirmed with histograms and boxplots. A Pearson Correlation (r=0.88-0.98, p<.001-.04) was performed to confirm similar force patterns between devices at all tested time points. Paired t-tests were performed to confirm no significant differences in force values between the Instron and the new testing apparatus with a level of significance set to p<.05. No significant differences were found (p=.13 to p=.89) at all time points between the two measuring machines.[36]

Bland-Altman plots (BAP) and Intraclass Coefficient Correlation (ICC) tests were also performed to verify accuracy and reliability of the new testing apparatus. The BAP showed all time points falling within the upper and lower limits of agreement. The ICC calculations confirmed that there was a high correlation of agreement between the gold standard Instron machine and the new apparatus.[36]

2.4 Pilot Testing

There were no reports found in the literature of twisting an elastic to see the effects it created on the force levels. One determination that had to be made prior to testing was how much to twist the elastic. To keep it clinically relevant, the twisting would need to be possible after placing the first end inside the mouth, as a patient would do. After running a pilot study testing 360° and 720° twists for 6 hours, the decision was made to test with a 720° twist. This would allow it to be clinically relevant and there would be enough twisting to show differences in force levels when compared to normal elastic placement.

2.5 Testing Methods and Data Collection

The apparatus was placed in a temperature and light controlled room. The load cells were calibrated before every test by a Shimpo Digital Force Gauge (Shimpo Model# FG-7002; Glendale Height IL, USA) with a 5 N load cell. The touchpad was used to select the desired water temperature (37°C), load cell read time (5min), cycle stretching time (1min), elastic manufacturer (OR, AO), elastic size (inches), manufacturer elastic force value (4.5oz, 6/6.5oz), material type (Latex), elastic color (Natural) and desired stretching distance (25mm).

The water bath consisted of distilled water with a pH of 5.9. The closed distilled water jugs were placed in a hot water bath to heat the water more quickly. The distilled water was then placed in the apparatuses water bath until the elastic hooks were completely covered and the desired temperature was reached. The temperature sensor then tracked the temperature, and it was automatically recorded every five minutes along with the force level data points from each elastic. The distilled water bath required topping up between tests and completely new water was placed initially and before testing of each manufacturer.

Sealed elastic boxes were opened and an elastic pouch was randomly selected for testing. Powder free neoprene examination gloves were used to open the elastic pouches when it was time to place them on the elastic stretching hooks. Several elastics were poured out onto a piece of paper and were visually inspected for damage, and gross discrepancies in shape, size, and thickness. Ten total elastics from one manufacturer (five elastics from each of the two separate lots) were selected and placed on the apparatus using non-serrated tweezers (Figure 5). The apparatus was immediately started after the last elastic was placed and the initial stretch distance was checked with a hand caliper prior to each group test. The elastic pouches were closed after extra air was expressed and were placed in the same, previously used, dark area at room temperature for later use. All 1/4”/4.5oz elastics used in the study (Groups 1, 4, 5, 6) were taken from the same two elastic pouches of the two distinct lots. All other elastics (Groups 2 and 3) were from different pouches and lots. When testing the 720° twisted elastics, a bamboo skewer was used with the tweezers to twist the elastic and place it on the two hooks, so to not damage the elastics in the process.

Figure 5: Ten elastics total (five elastics from each of the manufacturer's two separate lots) were selected for testing after being visually inspected.

2.6 Data Analysis

All data was collected on the micro-SD card of the testing apparatus. After testing was completed, the data was transferred to a computer where it was copied and pasted into excel for review. During the testing process there were specific load cells that periodically malfunctioned. In order to avoid any discrepancies, the data from these cells was carefully reviewed for any evidence of malfunctioning and removed when present. One hundred and twenty-seven samples of data were prepared for exporting to SPSS through organization, manipulation, and coding of the excel spreadsheet. The data was then uploaded to the statistical software program SPSS version 27 (SPSS, Inc., Chicago IL, USA) for analysis.

Descriptive statistics, including means and standard deviations, were calculated for each group and at each of the seven separate time points. These were cross checked with excel calculated means and standard deviations to confirm correct exportation to SPSS. Normality was reviewed through the Shapiro-Wilk test of normality and visually as histograms. Additionally, boxplots were used for detection of outliers. The majority of groups were normally distributed, and any significant outliers were checked for data errors. They were determined to be close in force values to the means and were likely due to random variation of elastics within the pouches used for the study.

A Two-Way Mixed Analysis of Variance (ANOVA) was run to determine interactions between the Group and Time variables. Mauchly's test of sphericity indicated that the assumption of sphericity was violated for the two-way interaction, $X^2 = 941.59$, $p = <.001$. Greenhouse-Geisser estimates were used for adjustments: $F(16.978, 177.496) = 64.283$, $p < .001$, partial $n^2 = .860$, $\varepsilon = .257$ and a statistically significant interaction between Group and Time was detected ($p<.001$). Once this interaction effect was confirmed, a between group One-Way ANOVA was performed at each time point, with a Tukey multiple comparison test, to detect differences between the groups. A repeated measures ANOVA was subsequently performed to analyze within group differences, over time, for each elastic group tested. This was followed by a pairwise comparison test of the time points, with a Bonferroni adjustment. The level of statistical significance was set at $p<.05$ for all tests performed.

Chapter 3

3 Results

When comparing the control elastic groups to the five modification groups, significant differences in force levels were noted at each time point ($p<.001$). For each elastic group, force levels between time points also showed significant differences ($p<.001$). Results of the pairwise comparisons between and within elastic groups are described below, according to each manufacturer. Lists of p-values can be found in the appendix (Appendix E).

3.1 Ormco Elastics

Mean force level values were significantly higher for groups OR2, OR4, and OR6 at all time points when compared to the control group OR1 ($p<.001$) (Table 4, Figure 6). Between the three groups OR4 had the highest mean force level values, while group OR6 had the lowest mean force values (except at T-1). Group OR3 showed significantly higher mean force values than group OR1 only early on, at time points T-1 and T-5 ($p<.001$ and $p=.025$). Group OR5 had mean force values that were significantly lower than group OR1 from T-5 until T-180 ($p=.001$ to $p=.046$).

	Groups					
Time	**OR1**	**OR2**	**OR3^**	**OR4**	**OR5***	**OR6^**
T-1	143.0 (7.1)	193.9 (12.8)	171.4 (9.9)	282.2 (12.5)	131.4 (7.8)	200.5 (10.5)
T-5	120.1 (6.1)	164.3 (10.3)	131.5 (8.6)	238.4 (10.0)	104.7 (6.9)	144.7 (7.3)
T-30	113.3 (6.2)	154.4 (9.6)	122.9 (8.7)	224.3 (9.4)	100.4 (6.5)	135.8 (7.3)
T-60	111.5 (6.1)	152.4 (9.6)	120.9 (9.1)	220.6 (9.5)	99.6 (6.3)	133.0 (7.4)
T-180	109.9 (5.6)	150.9 (9.3)	118.3 (9.2)	214.2 (11.3)	98.9 (6.4)	130.4 (7.9)
T-360	109.8 (5.2)	150.0 (10.0)	117.8 (8.7)	213.4 (10.5)	99.3 (6.2)	130.2 (7.7)
T-720	110.4 (5.4)	149.6 (9.0)	118.8 (8.9)	212.7 (10.7)	99.8 (7.0)	131.4 (7.4)

n=10 per group unless otherwise stated
*n=11 per group
^n=12 per group

Table 4: OR Elastic Groups Mean Force in Grams (SD)

Figure 6: Mean Force (g) at each Time Point for OR Elastic Groups. Different letters signify statistically significant differences between groups ($p<.05$). Error bars represent standard deviation (SD).

Comparison of within group changes over time (Table 4, Figure 7) showed significant decreases in force levels when comparing each successive timepoint from T-1 to T-60 (p<.001 to p=.004) in all groups except OR5. Group OR5 force levels stabilized earlier, with significant decreases in force levels between each successive timepoint only up to T-30 (p<.001 to p=.002). Groups OR1 and OR6 continued to show significant decreases in force levels when comparing each successive timepoint until T-180 (p<.001 to p=.037) after which they stabilized.

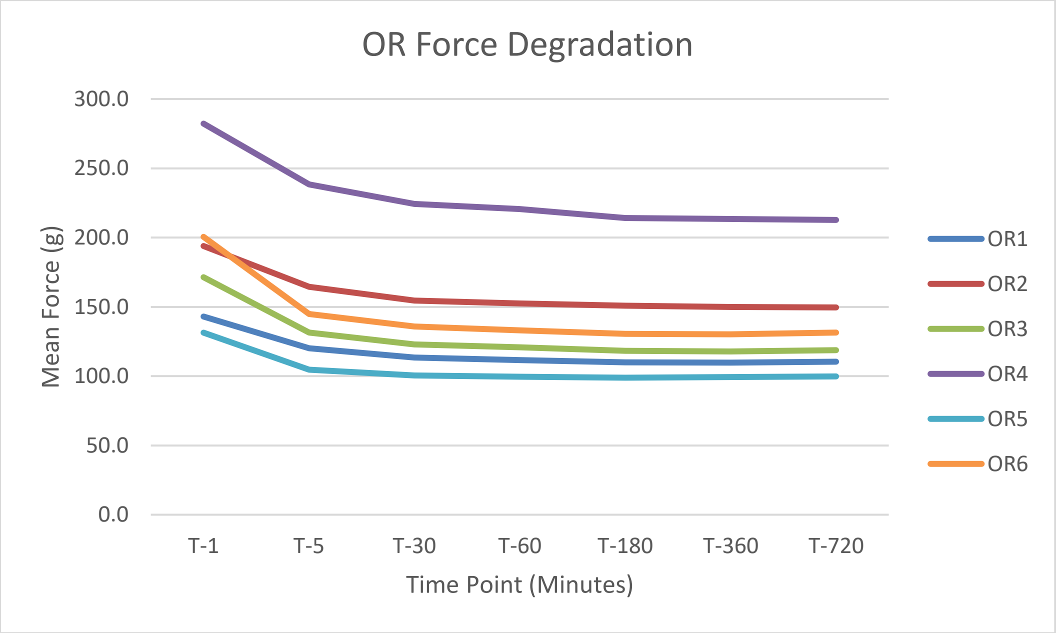

Figure 7: OR Elastic Groups Force Degradation Over Time

The largest decrease in force level values was seen from T-1 to T-5 in all OR groups (Table 5). Group OR6 showed the greatest decay with only 72% of original force value remaining at T-5, with group OR3 next at 77%, followed by group OR5 at 80%. The highest amount of force degradation over all time points was also seen in group OR6 at 66% of original force value remaining followed by group OR3 at 69%. All other groups had at least 75% original force values remaining at T-720. Force degradation values from T-5 to T-720 were only 4% for group OR5 and 6% for group OR6 while the remaining groups ranged from 7-9%.

	Groups					
Time	OR1	OR2	OR3	OR4	OR5	OR6
T-1	100%	100%	100%	100%	100%	100%
T-5	84%	85%	77%	84%	80%	72%
T-30	79%	80%	72%	79%	76%	68%
T-60	78%	79%	71%	78%	76%	66%
T-180	77%	78%	69%	76%	75%	65%
T-360	77%	77%	69%	76%	76%	65%
T-720	77%	77%	69%	75%	76%	66%

Table 5: OR Elastic Groups Percentage of Original Force Remaining

3.2 American Orthodontics Elastics

Force level values were significantly higher for Groups AO2, AO4, and AO6 at all time points when compared to the control group AO1 (p<.001 to p=.036) (Table 6, Figure 8). Between the three groups OR4 had the highest mean force values, while group OR6 had the lowest mean force values (except at T-1). Groups AO3 and AO5 did not have any significantly different mean force values at any time points when compared to group AO1 (p=.28 to p=.98).

	Groups					
Time	AO1	AO2	AO3	AO4	AO5	AO6^
T-1	178.5 (20.2)	219.5 (26.0)	200.4 (5.8)	350.5 (35.3)	166.3 (10.3)	247.4 (24.6)
T-5	152.4 (17.6)	191.0 (21.3)	158.5 (4.4)	299.7 (30.3)	135.2 (8.1)	177.7 (18.8)
T-30	141.2 (16.3)	177.6 (19.5)	147.3 (3.7)	277.8 (27.2)	126.7 (7.1)	165.5 (17.7)
T-60	138.6 (15.8)	174.2 (19.2)	144.5 (3.7)	272.5 (26.4)	124.9 (6.4)	161.8 (17.3)
T-180	136.6 (15.1)	171.3 (18.6)	141.5 (3.6)	267.1 (24.4)	124.1 (5.5)	158.8 (17.2)
T-360	136.1 (15.2)	170.9 (18.3)	140.9 (3.8)	264.7 (23.9)	124.3 (5.4)	156.9 (17.3)
T-720	135.2 (15.6)	168.6 (17.8)	140.3 (4.1)	262.4 (24.4)	124.8 (6.0)	157.2 (16.8)

n=10 per group unless otherwise stated
^n=12 per group

Table 6: AO Elastic Groups Mean Force in Grams (SD)

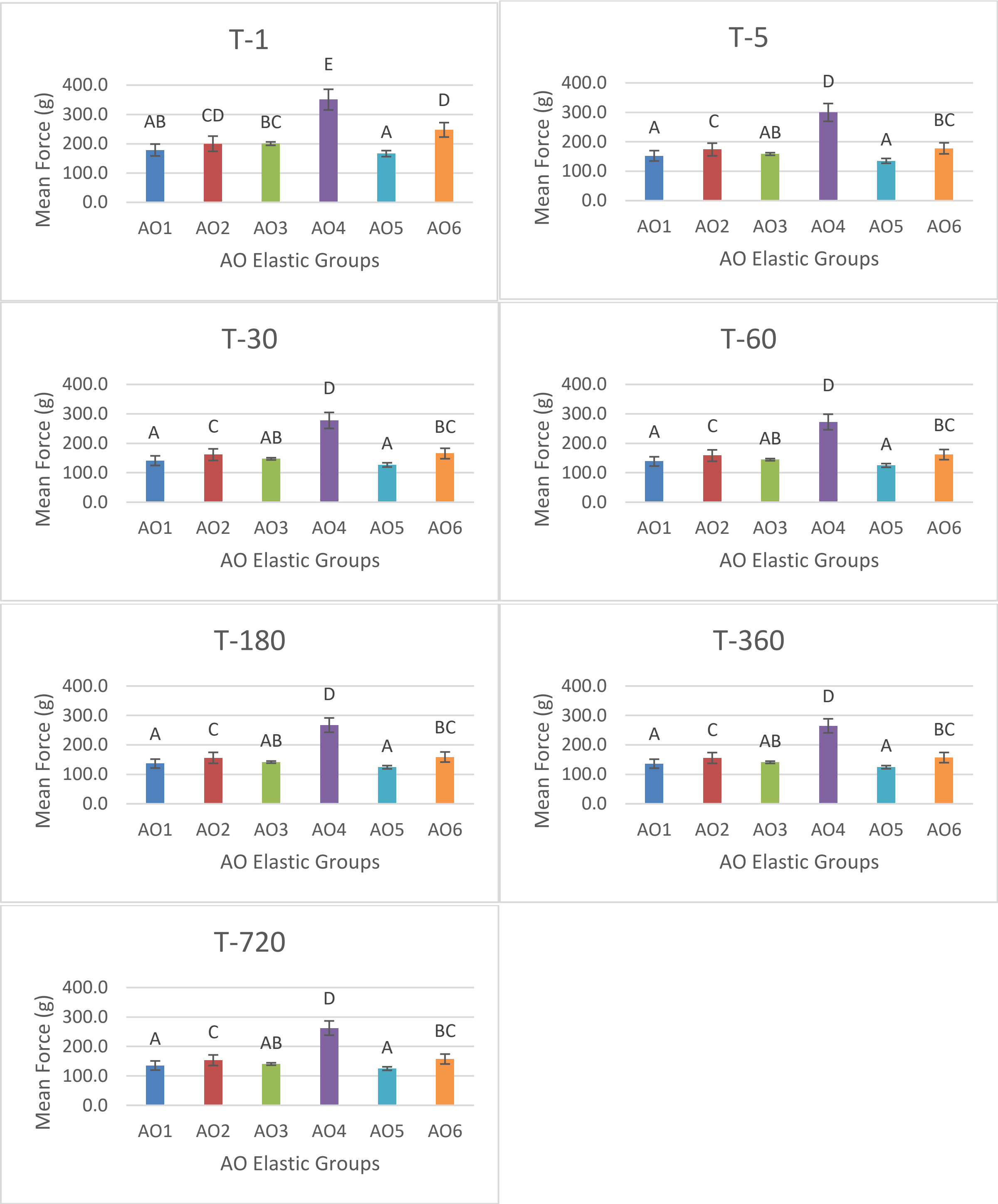

Figure 8: Mean Force (g) at each Time Point for AO Elastic Groups. Different letters signify statistically significant differences between groups ($p<.05$). Error bars represent standard deviation (SD).

When analyzing within group changes over time (Table 6, Figure 9), all AO elastic groups except for group AO5 showed significant decreases in force levels when comparing each successive timepoint from T-1 to T-180 (p<.001 to p=.029). Group AO5 showed force levels stabilizing earlier, with significant decreases in force levels between each successive timepoint only up to T-60 (p<.001 to p=.01). Groups AO4 and AO6 continued to show significant decreases in force levels when comparing each successive timepoint until T-360 (p<.001 to p=.008) after which they stabilized.

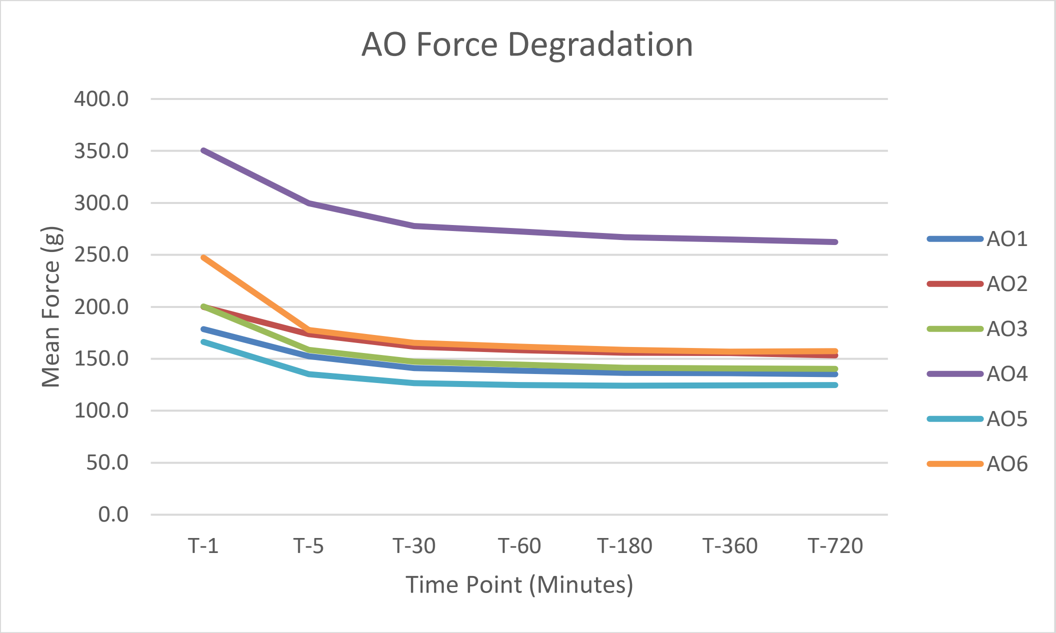

Figure 9: AO Elastic Groups Force Degradation Over Time

The highest force degradation occurred in the first five minutes within all AO elastic groups (Table **7**). Initial force degradation from T-1 to T-5 was greatest in group AO6 with only 72% of original force value remaining. Group AO3 was next at 79% and then group AO5 at 81%. The highest amount of force degradation at the end of all time points was seen in group AO6 at 64% of original force value remaining followed by group AO3 at 70%. All other groups had at least 75% original force values remaining at T-720. Force degradation values from T-5 to T-720 were only 6% for group AO5 and 8% for group AO6 while the remaining groups ranged from 9-11%.

	Groups					
Time	AO1	AO2	AO3	AO4	AO5	AO6
T-1	100%	100%	100%	100%	100%	100%
T-5	85%	87%	79%	86%	81%	72%
T-30	79%	81%	74%	79%	76%	67%
T-60	78%	79%	72%	78%	75%	65%
T-180	76%	78%	71%	76%	75%	64%
T-360	76%	78%	70%	76%	75%	63%
T-720	76%	77%	70%	75%	75%	64%

Table 7: AO Elastics Percentage of Original Force Remaining

3.3 Comparing Results in Different Manufacturers

In general, the AO elastic groups tended to have more variation in force levels (larger standard deviations), than the OR elastic groups. This appeared to be due to differences in recorded force levels between the two different lots in the randomly selected 1/4”/4.5oz elastics. These same elastics were used in groups AO1, AO4, AO5 and AO6 testing. The mean force levels and standard deviations by lot confirm the large variations. Lot 1 from group AO1 had a mean force level of 195.9g and a SD of 11.85 at T-1. Lot 2 had a mean force level of 161.2g and a SD of 5.01 at T-1. This difference was statistically significant (p<.001 to p=.009) at all time points.

Lot 1 from group AO2 had a mean force level of 201.4g and a SD of 12.90 at T-1. Lot 2 had a mean force level of 237.5g and a SD of 23.12 at T-1. Group AO2 also showed statistically significant differences between lots at all time points (p=.015 to p=.019). There were two other groups, OR3 and OR6, that showed significant differences between lots but their absolute differences were much lower (10.3-15.6g) over all time points than groups AO1 and AO2 (22.9-36.1g).

Force levels were consistently higher in AO groups when compared to the same OR groups at all time points (AO1/OR1 p<.001 to p=.001, AO2/OR2 p=.004 to p=.042, AO3/OR3 p=.002 to p=.009, AO4/OR4 p<.001, AO5/OR5 p<.001 to p=.001, AO6/OR6 p<.001). The only exception was AO2 and OR2 at T-1 (p=.06). The force level and degradation comparisons between same manufacturer groups showed similar trends in both OR and AO (Figure 6, Figure 8). An exception was the relationships between groups OR2/OR6 and groups A02/AO6, which differed at T-1 in that group OR2 started at a similar mean force level to group OR6 while group AO6 started at a much higher mean force level than group AO2.

Chapter 4

4 Discussion

Intraoral elastics are one of many ways to place force on a tooth or teeth to produce tooth movement. They are a valuable adjunct to orthodontic treatment and used so often, it has been stated that not considering their use is an injustice to the patient.[24,26] Previous studies looking at intraoral elastics show that force levels degrade over time and patient compliance might also be a concern, but there are also many advantages. Examples include their low cost, versatile use, ease of insertion, biocompatibility, and the variety of force levels and sizes that are available. These are all important reasons for their prevalent use today.[28,30,32,37,38,41,53]

The purpose of this study was to assess proposed alterations to intermaxillary elastic wear in a Class II patient and determine the force level changes and degradation to those elastics over time. Once determined, these force levels and degradation patterns will help clinicians make the correct adjustments to elastic prescriptions, thereby maintaining optimal force levels for each individual patient to successfully accomplish the desired tooth movements. The five proposed modifications of the standard elastic prescription include: increasing the force level, decreasing the elastic lumen size, doubling the elastic, adding a 720° twist, and increasing the initial stretch distance by one tooth.

4.1 Methodology

The parameters of this study were selected based on the current literature on intraoral elastics. An in vitro format was used to control elastic degradation variables such as cyclic stretching, temperature, and environment factors such as wetness and pH. The in vitro format also removed individual variations that might mask differences between patients such as mouth opening frequencies and distances, compliance, and diets. Thus, the focus can be placed on the basic physical properties of the elastics. Clinicians who use this information to adjust their clinical recommendations should also account for individual patient variables, such as mouth opening and compliance, in the decision-making process. Other variables such as material composition of elastics, added pigmentations, and increased degradation in vivo should also be considered.[4–6,22,27,28,30–32,35–47]

Wilson[36] created his apparatus to record force levels every five minutes. Other studies used more lengthy time points. These were as short as 15min,[36,48,54] 30min,[28,36,44,61] 1 hour,[27,30,32,34–37,39,42,45,47,53] or longer.[29,36,38,41,43,57,58,62] For this study, data analysis was performed at similar time points as those included by Wilson,[36] including 1min, 5min, 30min, 60min, 180min (3hr), 360min (6hr), and 720min (12hr). Time point 0min was not used because the apparatus required multiple initial readings for better precision and a period of elastic relaxation was also desired. Time points 180min and 360min were chosen due to these being possible end points when a patient would remove their elastics for eating. The 720min time point was chosen as the final point since this is likely the longest interval an individual elastic might be worn if placed before bedtime and removed in the morning. The selection of initial time points 5min, 30min, and 60min were included to evaluate the large initial decreases in force levels and the successive leveling off that have been reported in the literature.[12,27–30,32,34–38,41,43–45,53,61,62]

Cyclic stretching of the elastics was used in this study to imitate talking, yawning, parafunction, postural positioning of the mandible, and even eating in some compliant patients. The literature shows that cyclic stretching increases force level degradation.[28,47,48] Cyclic stretching is a better representation of the oral cavity during the daytime. Elastics worn at nighttime typically won’t be stretched as often and should not degrade as quickly, although a patient who partakes in excessive bruxism might be an exception. Another variable addressed in this study was a wet environment. Distilled water was used due to ease of access and because previous research showed no significant difference in force level degradation of elastomeric chain when comparing immersion in distilled water and artificial saliva.[63–65]

OR and AO elastics were selected for this study for many reasons. They are both large orthodontic suppliers in the United States and are common elastics used worldwide. They share the same manufacturer reported force level (4.5oz) for our control elastic and they were easy to acquire. They are also very prevalent in the literature that is currently available on intraoral elastics and have been tested in many previous studies.[12,14,28,29,31–34,36,42,43,47,49,51,53,56,66]

4.2 Elastic Force Levels Without Modifications

Manufacturers recommend that elastics be stretched three times their lumen length. Ormco and American Orthodontics report force levels in both grams and ounces on their pouches and/or elastic chart guide. When following the three times lumen length recommendation, a 1/4” elastic would be stretched the distance of 19.1mm. Mansour[49] measured Class I study casts and found a mean distance of 22.3mm between maxillary canine and mandibular first molar.

Due to the desire to make this study clinically relevant, the mean distance from the maxillary canine to the mandibular first molar of a Class I patient was extended 1.5mm to simulate the use of elastics to correct the bite in a mild Class II malocclusion. As such, the 1/4” elastic used for most of the modification groups was stretched to 3.74 times the lumen size. Groups OR2 and AO2 were smaller diameter 3/16” elastics and were stretched 5.00 times the lumen size for the initial stretch length. Groups OR6 and AO6 were the modification groups that involved adding an additional tooth clinically to the initial stretch length, increasing it to 38.1mm. This 1/4” elastic was stretched 6.00 times the original lumen size.

Ormco reports an expected force level of 130g when stretching a 1/4”/4.5oz elastic three times the lumen length. Wilson[36] reported an OR initial mean force level of 122.7g at three times the lumen length for the same elastic. Mansour had an initial mean force level of 116.0g at three times the lumen length and 136.7g at the 22.3mm distance for Ormco 1/4”/4.5oz elastics. The group OR1 initial mean force level in this study was 143.0g which includes the 1.5mm extra stretch over Mansour’s 22.3mm distance and 4.7mm extra initial stretch over three times the lumen recommendations while using the same apparatus as Wilson. The initial force level of 143.0g from this study appears consistent with the previously reported numbers when accounting for the additional stretch applied to the elastic.

American Orthodontics reports the same 1/4”/4.5oz elastic at an expected force level of 125g. Wilson[36] reported an initial mean force level of 120.2g at three times the lumen length for this same elastic. Mansour had an initial force level of 122.8g at three times the lumen length and 145.0g at the 22.3mm distance for American Orthodontics 1/4”/4.5oz elastics. The group AO1 initial mean force level in this study was 178.5g which includes the 1.5mm extra stretch over Mansour’s 22.3mm distance and 4.7mm extra initial stretch over three times the lumen recommendations. This value is higher than previous studies and is likely due to a combination of the increased initial stretch length and the significantly higher initial mean force levels in lot 1 (195.9g) of group AO1 elastics compared to lot 2 (161.2g). Ardani et al[42] reported an initial mean force value of 249g for the 1/4”/4.5oz American Orthodontic elastic when dry stretching it 30mm and diagonally at a 20° angulation. The expectation of a higher stretch length would be a higher force level, as seen here. Fernandes et al[33,34] also stretched American Orthodontic 1/4”/4.5oz elastics 30mm. They reported initial mean and medium force values from two different studies at 192.6g and 192.5g respectively. The force levels in the current study were within reported ranges from previous studies. Standard deviations for 1/4”/4.5oz American Orthodontic elastics in previous studies are all <10 which suggests the higher standard deviations in this study for AO was unique. .[28,33,36,42,49] This was specific to AO elastics and not OR in the current study.

4.2.1 Increasing Force Levels

An increase in force levels of one unit was applied to this modification. For OR elastics it was an increase from 4.5 to 6oz. AO elastics increased from 4.5oz to 6.5oz. This modification showed a significant increase in force levels over all time points for OR and AO groups. Initial mean force levels of 193.9g or a 35.6% increase of force levels were seen for group OR2 when compared to group OR1. Group AO2 had an initial mean force level of 219.5g or a 23.0% increase over group AO1. Group OR2 had a range of 50.9–39.2g increased force over all time points when compared to group OR1. Group AO2 had a range of 41.0–33.4g increased force over all time points when compared to group AO1.

Klabunde and Grünheid[40] tested 4.5oz and 6.5oz AO latex elastics during a project to evaluate static versus dynamic stretching and the resultant force decay. They reported initial force levels of 127.3g (4.5oz) and 174.1g (6.5oz) in their dynamic stretching elastics. A range of 46.8–30.6g increased force levels between the elastics was found, with the same time points as this study. This is similar to the increased force levels in this study when increasing the elastic force by one unit. Force degradation percentages were also calculated from Klabunde and Grünheid’s data. Force levels remaining after 720min were 69% (4.5oz) and 68% (6.5oz) while this study showed 76% (4.5oz) and 77% (6.5oz) remaining respectively. The difference in force degradation is likely due to the increased cycling of the elastics by Klabunde and Grünheid. They cyclically stretched at a frequency of 360 cycles per hour while this study had a cyclic stretch frequency of 60 cycles per hour. The within group changes over time for OR2 show forces stabilizing around T-60 while AO2 continues to degrade until T-180.

4.2.2 Decreasing Lumen Size

A decrease in lumen size was applied for this modification. The 1/4” lumen was decreased one unit to 3/16” lumen size. Groups OR3 and AO3 incorporated this modification, thus increasing the initial stretch distance above the manufacturers and Mansour’s recommended lengths. Mansour[49] reported an initial force level of 156.8g for OR 3/16”/4.5oz elastics and 147.7g for AO 3/16”/4.5oz elastics, both stretched to 22.3mm. When comparing these elastics to his equivalent initial mean force levels of 1/4” elastics, we see a 14.7% and 1.9% initial mean force increase. This study found 171.4g for OR at the 23.8mm initial stretch length and 200.4g for the equivalent AO elastic. Groups OR3 and AO3 saw an initial mean force increase of 19.9% and 12.3% over groups OR1 and AO1 respectively.

The current OR force level appears consistent with a 1.5mm increase in stretch length compared to Mansour’s length. The AO elastic initial mean force level increase in the current study is larger than expected. All AO elastics in this study have higher than expected initial mean force values which may suggest changes to or inconsistencies within manufacturing practices for AO elastics. Group OR3 was only significantly higher than the control elastic at T-1 and T-5 while group AO3 showed no significance in force level changes from the control elastic.

An initial increase in force degradation over time is seen in this modification of decreasing the lumen size. For groups OR3 and AO3, degradation of the elastic was greater from T-1 to T-5 when compared to groups OR1 and AO1, respectively. Groups OR3 lost 23% of its force levels in the first five minutes compared to 16% for group OR1. Group AO3 saw similar losses of 21% compared to 15% for group AO1. All other time points after T-5, in regards to elastic degradation, seem to stabilize similarly to the other modifications and the control elastics. The within group changes over time report a leveling off of degradation around T-60 for OR3 and T-180 for AO3. This is consistent with Lin et al[48] findings of elastic degradation happening in two distinctive phases. They found that in static stretching, an elastic's force level was significantly reduced after 15 minutes and that it was stabilized after two hours. Dynamic stretching showed a greater degree of force degradation at all time points than static stretching.

4.2.3 Doubling of Elastics

Placement of two elastics instead of one led to initial mean force levels of 282.2g or a 97.3% increase of force levels for group OR4 when compared to group OR1. Group AO4 had an initial mean force level of 350.5g or a 96.4% increase over group AO1. These increases are comparable to adding the individual force levels of each individual elastic. There were significant increases in mean force levels at all time points. Wilson[36] is the only study that reports on the doubling of elastics. These force level increases compared to groups OR1 and AO1 held well throughout the 720min which is what Wilson[36] also found to be true through 24 hours. Group OR4 was at 92.7% of group OR1 and group AO4 was at 94.1% of group AO1 force levels at the end of 720min in the current study.

Force degradation levels of group OR4 when compared to group OR1 are within 2% at all time points. Group AO4, when compared to group AO1 is even closer at 1% in this study. Wilson[36] found similar results with decay rates between single and double elastics being within 2% at all time points up to 720 minutes in American Orthodontic and Auradonics elastics. At 24 hours American Orthodontic elastics were still within 2% while differences between single and double Auradonics elastics had increased mildly to 3%. This seems to indicate that degradation of one elastic is similar to the degradation of two elastics placed in the same location. The within group changes over time show that group OR4 (T-60) stabilizes before OR1 (T-180) while AO4 (T-360) continues to degrade after AO1 (T-180) has stabilized.

Proffit et al[1] recommends 250g of force per side when using Class II elastics on rectangular archwires and displacing one arch relative to the other arch when changing the arch occlusion. Langlade[13] recommends 318g per side based on resorptive root surface. This modification of doubling the elastics was the group that was closest to the force levels recommended by these experts for elastic use to change occlusions. These groups also maintained these recommended force levels well throughout all timepoints. Oesterle et al[15] surveyed practicing orthodontists about Class II patients in rectangular wires and their recommended elastic prescriptions. Their answer was a mean of 277 ± 89g and a median of 256g. Groups OR4 and AO4 fit within one standard deviation of their response. This was found to be the best method in the current study to consistently increase force levels.

4.2.4 Twisting of Elastics

Groups OR5 and AO5 were the modifications of twisting the 1/4”/4.5oz elastic 720°, once one end of the elastic was attached to a bracket hook. This is a frequent modification used by orthodontists with the rationale being that by twisting the elastic, it would cause the elastic to act as a shortened lumen length and increase the initial force levels. The T-1 mean force levels for groups OR5 and AO5 were 131.4g and 166.3g respectively. The initial mean forces decreased, although not significantly, when compared to groups OR1 (143.0g) and AO1 (178.5g), decreases of 8.1% and 6.8% respectively. This trend continued throughout all time points with significantly lower force values found in group OR5 vs group OR1 from T-5 to T-180. The results from within group changes over time show elastic degradation stabilizing the quickest out of all modifications tested, with force levels for groups OR5 stabilizing at T-30 while AO5 stabilizes at T-60.

There are no previous reports of twisting elastics in the literature. The methodology of placing these twisted elastics was technically more difficult and required more time for placement as compared to the other modifications, which might be an issue for some patients. This extra difficulty and time do not appear to increase force levels as desired but appears more likely to do the opposite and decrease them at all time points. One possibility of why the force levels obtained are lower might be due to increased friction at the center of the elastic leading to decreased stretching in these areas, and an overstretching of the elastic fibers at the ends attached to the hooks. This would create a similar effect to groups OR3/AO3 and OR6/AO6, although to a much greater effect whereby the elastic fibers of the hook ends of the twisted elastic are pushed past their elastic limit and permanently damaged, leading to overall weaker force levels. More research is needed in this area to fully understand the response seen with twisting of the elastic.

4.2.5 Increasing Initial Stretch Length

This modification required adding an additional tooth to the initial stretch length. This would most likely be the mandibular second molar but could also be the addition of the maxillary lateral incisor in the anterior. Both groups OR6 and AO6 showed significantly higher forces than groups OR1 and AO1 over all time points. Initial mean force levels of 200.5g and 247.4g were found, as were initial mean force increases of 40.2% and 38.6% respectively, when compared to the control groups. Mansour[49] reported findings for OR and AO 1/4"/4.5oz elastics at 22.3mm and 38.7mm, and found similar increases in force levels as the current study when the elastic stretch distance was increased. At 22.3mm force levels were 136.7g for OR and 145.0g for AO. At 38.7mm, force levels were recorded at 168.7g for OR and 185.7g for AO. This resulted in a 23.4% initial mean force increase for OR elastics and a 28.1% increase for AO elastics in the study.

Mansour reported that there was a continuous and significant increase in force for 1/4"/4.5oz elastics from three times the lumen length (19.1mm) up to the 38.7mm stretch length. The two lengths of stretching between Mansour's study and this one differs for both lengths making it difficult to compare them with each other. His study showed a difference in force between the two lengths of 32.0g for OR elastics, and 40.7g for AO elastics. The current study found differences of 57.5g between groups OR6 and OR1, and 68.9g between groups AO6 and AO1. The absolute changes in the current study are higher than expected which is likely due to differences in methodology. The stretching of lumen size to 6.00 times the original lumen length in this study and Mansour's study stretching it even further, potentially initiating permanent deformation, may be another factor for the large variability. Proffit et al[1] describe latex elastics as having a useful performance life of four to six times the lumen length. An increase in stretch at these large lengths, eventually, pushes the elastic toward irreversible deformation and a decrease in force levels.

Elastic degradation in groups OR6 and AO6 was the highest of all modifications in this study for both initial and overall decay rates by percentage. Group OR6 lost an additional 12% of overall force levels within the first five minutes when compared to group OR1. Group AO6 was similar at 13% more force lost in the first five minutes when compared to group AO1. Within group changes over time show the elastic degradation of group OR6 stabilizing at T-

180 while AO6 levels off at T-360. The control elastics which experienced less of an initial stretch length, showed stabilization of force degradation after T-180 for both OR and AO groups. The current study is consistent with Lin et al[48] findings of elastic degradation occurring significantly after 15 minutes and then stabilizing. The current study suggests that significant degradation occurs within the first five minutes.

4.2.6 Manufacturer

Kanchana and Godfrey[29] tested four manufacturers (Unitek, Ormco, Tomy, and Dentaurum) in dry conditions to see the mean percentage variation from the standard elastic index of three times the lumen diameters of the elastics. They found Unitek at 29%, Ormco at 9.5%, Tomy at 41.9%, and Dentaurum at 13.1% more than their standard force index. This study showed group OR1 at 9.1% and group AO1 at 42.8% variation from the standard elastic index, keeping in mind that these control elastics were stretched 3.74 times the lumen length instead of the recommended three times. The current study suggests that Ormco was closer to the standard elastic index than reported by Kanchana and Godfrey.[29] American Orthodontics was much higher than the standard elastic index. This is likely due to the variations in the lots with higher force levels that were randomly selected and tested in this current study. The initial mean forces for group AO1 were 195.9g for lot 1 and 161.2g for lot 2.

Mansour[49] and Wilson[36] both reported on initial mean force levels and standard deviations for 1/4”/4.5oz OR and AO elastics. All factors considered, the current study has similar values of initial mean force levels and standard deviations for OR elastics as reported in these previous studies, while AO elastic force levels are higher in the current study. The higher AO force levels are likely due to larger variations in the elastics and differences between the two different lots that were randomly selected, one displaying significantly higher force levels than the other and both lots showing higher forces than the equivalent OR elastic. Manufacturing variation is another potential reason for the differences seen. A comparison of the current study and Mansour[49] 3/16”/4.5oz OR and AO elastics yield the same conclusions as the 1/4”/4.5oz elastics.

Wilson[36], Klabunde and Grünheid[40], and the current study reported force degradation levels at T-60, and T-720 for AO elastics that were similar. Additionally, Wilson and the current study reported the time point T-5 for AO elastics and T-5, T-60, and T-720 for OR elastics with similar trends overall. When manufacturers were compared in the current study using within group changes over time, elastic degradation stabilized at the same rate in groups OR1 and AO1 at T-180. All other groups stabilized sooner in OR elastics when compared to their AO equivalents. The time points of force stabilization for the remaining groups include, OR2 (T-60), AO2 (180), OR3 (T-60), AO3 (T-180), OR4 (T-60), AO4 (T-360), OR5 (T-30), AO5 (T-60), OR6 (T-180), AO6 (T-360)

Kamisetty et al[27] tested Forestadent, GAC, and Glenroe 1/4” latex medium force elastics. They found time points T-60 and T-720 showed remaining force levels for Forestadent at 84% and 78%, GAC at 82% and 74%, and Glenroe at 83% and 76% respectively. The literature is convincing that there are differences in initial mean force levels and degradation rates between manufacturers, likely due to materials used, and proprietary manufacturing methods. The results from the current study agree with this assessment. Despite the differences between manufacturers, there are general trends seen in this study in both OR and AO elastics, with similar responses to the modifications applied in each group. These general trends can be seen in both initial mean force levels and degradation of those levels through the 720min of data.

4.3 Clinical Implications

Increasing the force level of the elastic one unit, doubling the elastic, or adding an extra tooth to increase initial stretch length were the three modifications that showed statistically significant increases in force levels. The question of whether these increases in force levels imparted by these modifications are also clinically significant is a difficult one to answer. Due to the sheer number of variables that can affect tooth movement in Class II intermaxillary elastic correction cases, the answer is most likely to be individual dependent. Bone density and volume, root length, number, and surface area, individual anatomy, patient phase of growth, fibrous tissue variability, and previous trauma or current pathology are some of the many variables that can impact the clinical significance of elastic force levels.[8–11]

Langlade[13] discusses the different vertical and horizontal force levels seen in Class II patients when in centric occlusion compared to the mouth being open 10 or 25mm. Different force levels are seen between the mandibular and maxillary arches based on the changed mouth positions over time. He summarized that nighttime elastic wear has equivalent vertical and horizontal components while daytime wear has a much more significant vertical than horizontal component. Tooth type and direction of movement greatly influence the force levels needed for clinical significance.

Wilson[36] used a 15-20% difference between groups as his clinically significant force level due to the complication of variables in truly determining clinical significance. He discussed that clinical significance can be dictated on several variables, including the type of tooth movement attempted. Proffit et al[1] described the necessary force levels to move varied types of teeth in the different planes of space. Intrusion requires as little as 10-20g while bodily movement has a range of 70-120g of force. Ranges of force are presented due to smaller teeth, such as incisors, needing less force while multirooted posterior teeth require more for movement. Individual tooth movement requires less force than interarch tooth movement for which Proffit recommends 250g per side.

For the current study, the same 15-20% difference between groups was applied for clinical significance. Groups OR2, OR4, and OR6 all maintained at least 15-20% of additional force over the control elastic at all time points. The same can be said for the AO modification equivalents. Group OR2 had a range of 50.9–39.2g increased mean force levels over all time points. Group OR4 had a range of 139.2–102.3g and group OR6's range was 57.5–20.4g. When considering the range, it is important to remember that generally large decreases in force levels are seen in the first 5-30min followed by slow gradual decreases throughout the 720min.

When an orthodontist is modifying their 1/4" elastic prescription they should first consider potential reasons for the poor response. Poor patient compliance is a common one and should be ruled out. Others could be occlusal interferences which might require bite turbos to eliminate. Biomechanical side effects that are inhibiting the desired response, or orthodontic adjuncts that are limiting the desired movement should be addressed first as well. The orthodontist should also consider common limitations of the anatomy such as cortical bone, lip and tongue pressures, and limits of arch corrections such as excessively proclined or retroclined incisors.

If, after considering and ruling out these types of potential reasons for an inadequate effect, the orthodontist should then consider force levels and determine if they are the reason for the poor response. If there is a good chance that they are, the orthodontist should determine whether a small, moderate, or large increase in elastic force levels is needed. The results of this study suggest considering the following options:

> Small Increase in Force Levels: The addition of an extra tooth to the elastic (Groups OR6/AO6).
>
> Moderate Increase in Force Levels: Can be achieved by increasing the force levels by one unit (Groups OR2/AO2).
>
> Large Increase in Force Levels: Doubling the elastic (Groups OR4/AO4) will accomplish this.

The orthodontist should consider potential problems when considering increases in force levels. Increasing force levels excessively, when it is not needed can lead to problems such as root resorption, TMD, excessive or unwanted tooth movements, and more undesirable side effects from vertical vectors to name a few. Due to the variety of sizes and force levels available on the market, the orthodontist should remember there are many other options available as well.

Force degradation is a part of using elastics in the practice of orthodontics. Most degradation occurs quickly after elastic placement followed by relatively constant force levels. This should be considered when deciding on what force levels are desired. Statistical analysis of groups OR2, OR4, and OR6 showed elastic degradation stabilization at T-60, T-60, and T-180 respectively. Groups AO2, AO4, and AO6 were much more variable in the stabilization of elastic decay with results at T-180, T-360, and T-360. Clinically, the absolute values of degradation were minor, sometimes as low as 2-3g, while still showing statistical significance. When considering clinical significance, elastic degradation stabilizes at the T-5 or T-30 time points.

When looking at percentages of force degradation levels, this study found 21-35% degradation after the first hour for all OR and AO groups combined, with only minor differences between OR and AO. After 12 hours these levels changed very little to 23-36%.

Kanchana and Godfrey[29] reported general force degradation numbers after studying four manufacturers. They reported around 30% after one hour. They did not report at 12 hours but reported 32.6% after 24 hours. Wilson[36] reported on three manufacturers with around 23% force degradation in one hour and 28% after 12 hours. Qodcieh et al[45] reported 50% force degradation within four to five hours from 3/16” Class II elastics in vivo.

The more often the elastics are changed the higher the overall force levels will be. Having a compliant patient increase the frequency of changing the elastics for new ones is another strategy to increase force levels in the non-responsive patient when initial response is poor. Nitrini et al[46] recommend that patients change their elastics every 24 hours. Alavali et al[61] said that non-latex elastics should be changed even more frequently at what they referred to as several times a day. Qodcieh et al[45] concluded that daily changing of elastics is best for oral hygiene and to limit breakage. The frequency of elastic changes should be incorporated into the elastic prescription. The current study recommends that elastics be changed a minimum of once every 12 hours.

4.4 Strengths and Limitations of the Study

This study addressed a common clinical question to which recommendations might be made based on the results. Other strengths include trying to incorporate the different known variables that affect elastic degradation. By doing an in vitro study, the variables of cyclic stretching, temperature, pH, and wetness were controlled in the created environment meant to imitate the oral cavity. Parameters were chosen based off the current literature available to allow for ease of comparing studies through the different variables. The custom apparatus fabricated by Wilson,[36] allowed for efficient and effective measurements and tracking of important information such as time, temperature, and force levels. The use of elastics from two manufacturer’s allowed for a comparison of trends seen within the modifications to verify the expectation of seeing these trends throughout all manufacturers.

The most obvious limitation to this study is the in vitro research model used. An in vivo study would allow for easier comparisons to clinically relevant modifications. It would also eliminate the potential discrepancies created by trying to recreate the environment with limited knowledge on many of the variables, that the in vitro study was used to control in the first place. Additionally, true elastic force degradation would be shown, similar to the current literature which shows increased elastic force degradation in intraoral studies.[35,44,45] Other limitations include the limited number of elastic sizes and force levels tested. A limited number of manufacturers were also tested to compare trends. The testing of more manufacturers would confirm or reject the trends being seen across the orthodontic elastic marketplace.

4.5 Future Research

Potential research in the future could help address the in vivo effects on the force level degradation seen through the modifications presented in this study. Trends seen in this study could be replicated and expanded into different elastic sizes and manufacturers. A split mouth study on Class II patients and the effects of different force levels on Class II correction may help us better understand the spectrum of clinical relevance in orthodontic elastic usage. The same can be said for Class III patients as well as other types of malocclusions in other planes of space. There is a lot of information to still discover on the use of orthodontic elastics, force level degradation and the variables involved in the degradative process.

Chapter 5

5 Conclusion

An in vitro study was conducted to compare different prescription modifications in the use of intraoral orthodontic elastics for the correction of Class II malocclusions from two manufacturers. They were tested for changes in mean force levels and degradation patterns over a period of 12 hours. Based on the results of this study, it was found that:

1. Increasing a 1/4" elastic from 4.5oz to 6/6.5oz significantly increased force levels at all time points and in both manufacturers
2. Applying two 1/4”/4.5oz elastics instead of one significantly increased force levels at all time points and in both manufacturers
3. The addition of one extra tooth to the initial stretch length of a 1/4”/4.5oz elastic significantly increased force levels at all time points and in both manufacturers
4. The addition of twisting to a 1/4”/4.5oz elastic significantly decreased force levels in one manufacturer
5. Decreasing the size of the elastic from 1/4" to 3/16”, or increasing its stretch by one tooth, led to increased levels of percentage force degradation over time in both manufacturers
6. In general, elastic force degradation tended to stabilize between 60 and 180 minutes

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Appendices

Appendix A: Raw Force Level Data (g) for Ormco (OR) Elastics

	T-1	T-5	T-30	T-60	T-180	T-360	T-720
OR1	152.5	129.6	124.1	121.7	118.4	116.6	118.5
	131.8	111.7	105.7	104.2	103.8	105.4	107.4
	142.7	122.1	114.9	113.1	110.3	110.2	110.6
	151	127.4	120.5	118.1	116	116.3	117.9
	141.2	117.5	111	109.3	108.3	107.8	108.9
	149	123.8	117.2	115.9	114.5	113.3	113.6
	134.9	113	105.6	103.3	101	100.1	102.6
	135.8	113.7	107.4	105.9	106.1	107.7	106.2
	143.9	120.8	114.7	113.2	112.7	113.5	113.1
	147.1	121	112.2	109.9	107.6	106.6	105
OR2	182.8	169.1	159	155.8	152.4	151.1	151.2
	187.5	158	148.1	145.4	141.4	134.4	137.9
	201.1	169.9	159.9	157.5	155.8	155.8	154.3
	194.3	163.6	154.8	152.1	150.8	147.3	146.1
	216.8	180.4	167.2	165	162.7	163.8	162.7
	209.7	176.4	166.9	166.3	165.5	165.3	163.7
	195.9	166.6	157.5	155.8	154.9	153.9	153.1
	194.2	159.3	148.2	146.8	146.1	145.4	143.3
	178.8	153.2	145	143.1	142.3	143.5	144.1
	177.8	146.9	137.7	136.4	137.1	139.3	139.3
OR3	162.3	123.7	115.7	113.6	111.3	110.8	111.9
	154.8	118.5	110.3	106.3	105.4	104.1	104.7
	161	120.2	112.5	109.9	109.2	109.5	109.8
	164.5	126.7	117.4	117	115.4	114.8	114.5
	168.9	126.3	116.1	112.5	110.4	110.6	112.3
	188.8	145.8	136.8	134.9	133.7	132.6	132.1
	175.5	136.1	130.5	129.7	129	127.5	127.8
	178.7	136.5	127	125	124.5	122.5	121.6
	172.7	131.7	121.3	121.8	111.2	114.2	114.4
	183.9	142.9	134.3	131.9	127.4	125.5	129
	169.8	132.3	124.3	121.6	117.7	115.9	118.5
	175.6	137.2	128.8	126.5	124.6	125.6	128.6
OR4	257.6	218.6	206.3	202.4	190.8	191.3	191
	289.5	245.7	231.9	228.1	206.7	209.8	208.7

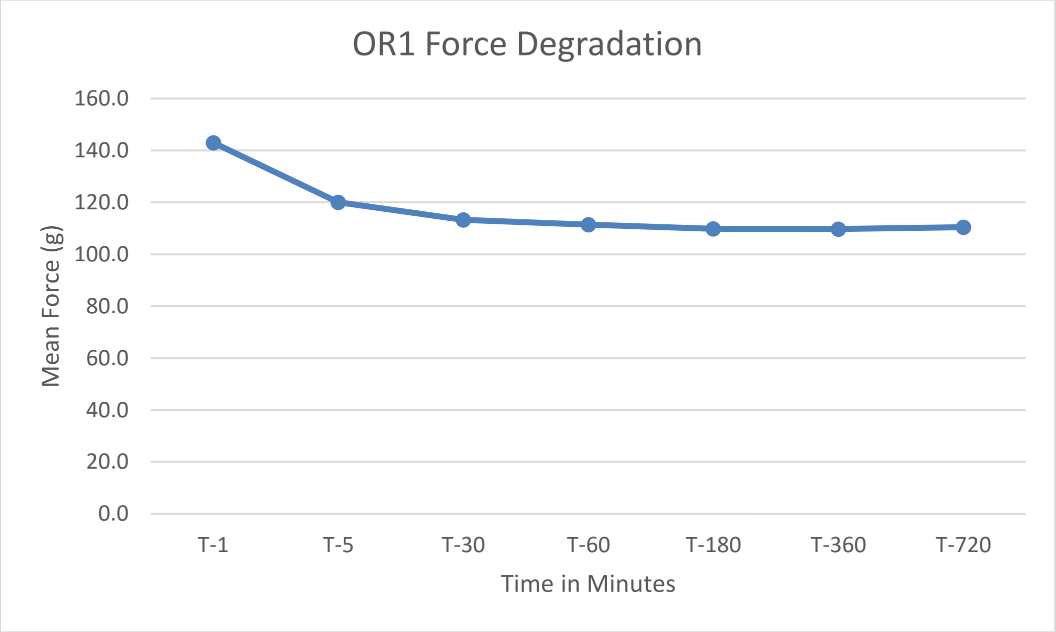
	279.5	237.6	225	221.6	218.9	219	218.2
	277.5	235.8	222.8	218.9	215.4	213.8	211.5
	289.3	244.1	228.7	225.4	221	219.5	219
	277.3	232.5	217.7	213.6	208.9	207.6	206.6
	278	234.3	220	215.7	211.1	208.5	208.2
	304.6	255.6	240.9	237.5	233.3	231.2	231.9
	276.7	234.3	220.1	216.5	213.4	213.2	212.8
	292.1	245.9	229.7	226.1	222.3	220.5	219.2
OR5	125.6	93.9	94.5	97.3	96.2	97.1	92.4
	132.5	103.2	101.6	99.9	98.7	99	95.5
	117.1	101.7	96.7	95.8	96.4	99	99.3
	133.1	103.7	100.7	99.6	99.2	100.7	100.6
	128.7	105.3	99.7	98.7	98.3	98.9	100.6
	135.9	114.8	111.7	110.5	109.2	109.5	110.6
	138	103.8	97.2	95.2	92.4	91.6	93.1
	121.3	94.7	89.4	88.6	88.4	88.9	91.3
	144.4	106.3	99.9	98.8	97.6	97.2	97.9
	131.5	108	102	100.6	100.8	101.4	104.1
	137	116	111	110.4	110.4	109.3	112.4
OR6	189.7	136.2	128.6	126.2	122.4	120.6	123.6
	182.9	134.4	125.7	122.6	120.3	122	124.9
	194.3	140.9	133.1	130.8	128.4	127.5	128.4
	204.3	146.8	136.4	132.2	128.8	128.5	131.5
	205.2	149.2	140.2	137.1	133.6	133.8	135.3
	218.8	157.2	151.3	149.6	148.2	146.7	148
	208.7	147.7	135.6	131.2	126.4	126.4	126.7
	197	141.5	131.8	128.3	127.6	130.6	130.8
	189.7	135.2	127.6	126.8	125.1	124.4	124.6
	197.4	144	134.9	132.1	128.1	125.5	126.5
	211.9	151.6	142.1	139.5	138.6	138.5	139.9
	206.3	151.9	142.1	139.6	137.8	137.7	137.1

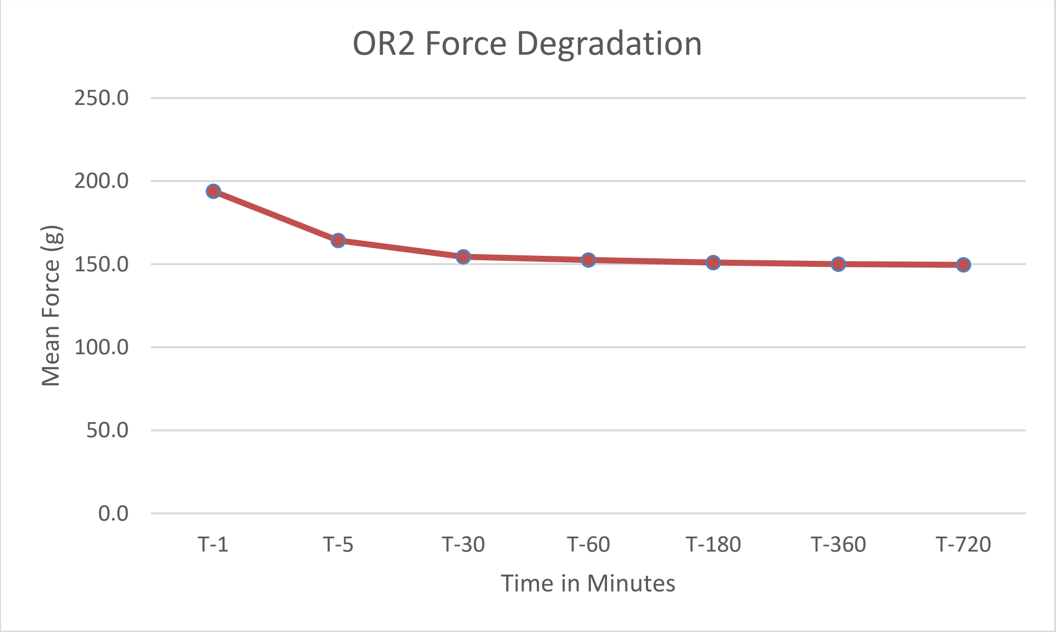
Appendix B: Raw Force Level Data (g) for American Orthodontics (AO) Elastics

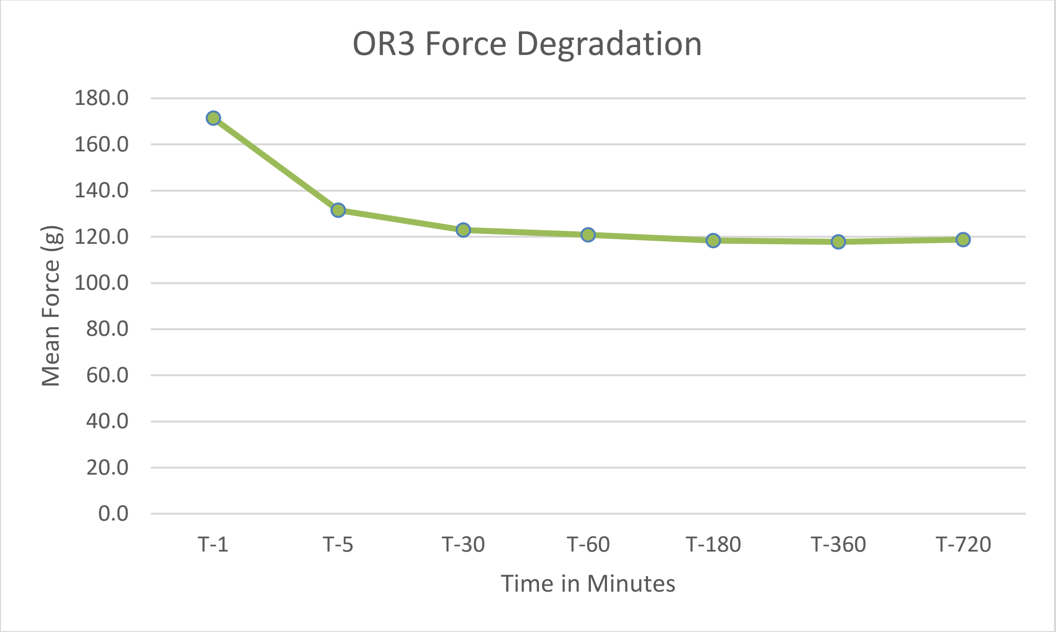
	T-1	T-5	T-30	T-60	T-180	T-360	T-720
AO1	200.6	173.3	161	157.6	153.5	152.7	152.5
	185	149.4	136.5	135.4	131.1	126.7	124.7
	207.6	179.1	166	162.5	160.8	161.4	160.9
	204.8	175.7	162.5	159.4	156.5	155.5	153.9
	181.6	155.6	144.7	141.3	139.8	140.2	141.1
	169.7	144.7	134.8	132.8	131.3	132	130.9
	157.3	135.9	126.7	124.5	123.5	123.7	123.8
	161.1	138.4	128.1	125.4	122.5	122	121.1
	157.9	135.3	126.1	124.1	123.9	124.1	123.4
	159.8	136.1	125.2	123.3	122.8	122.7	119.4
AO2	195.2	172.7	161	157.7	154.1	153.9	152.8
	184.1	163.8	153.6	150.8	149.9	150.8	148.5
	218.7	190.8	177.2	173.5	169.9	168.4	166
	206.7	179.8	166.4	163.1	161	162.3	161.1
	220.6	190.2	177	173.9	172.3	173	170.2
	250.3	218.3	203.3	199.6	195.7	194.9	192.8
	205.4	178.4	166.4	163.3	160	158.4	157.1
	256.7	222	206.7	203	199.9	198.8	195.5
	202.3	175.6	162.8	159.4	156.7	155.3	152.5
	254.5	218.8	202	197.7	193.9	193	189.1
AO3	206.1	165	153.6	149.8	144.8	143.2	143.1
	200.7	156.7	145	142.1	140.2	140.5	140.4
	191.9	152.4	142.6	139.4	136.6	135.5	134.3
	200.7	159	145.2	142.6	139.4	139.2	140.5
	204.9	162.9	151.4	149.1	145.4	144.6	145
	196.1	153.2	144.3	142	138.9	137.8	137.2
	201.7	159.1	146.5	142.8	137.6	136	134.8
	199.1	161.3	150	147.9	145.7	146	145.5
	192.5	153.7	144.2	141.8	140.9	140.3	138.4
	210.2	161.7	150.6	147.7	145.7	145.5	144.1
AO4	379.7	328.9	305.4	297.6	287.9	283.7	288.6
	381.7	326.1	303.1	296.5	290.9	289.5	288.4
	379.2	323.2	296.6	295.1	288.9	286.5	280.2
	355.9	302.9	280.5	274.8	270.3	269.6	268.3
	317.1	271.7	253.7	249	245	242.7	240.5
	345.1	295.1	272.6	266.8	260.8	258.7	255.5
	305.1	261.2	242.9	238.2	234.2	231.7	229.5

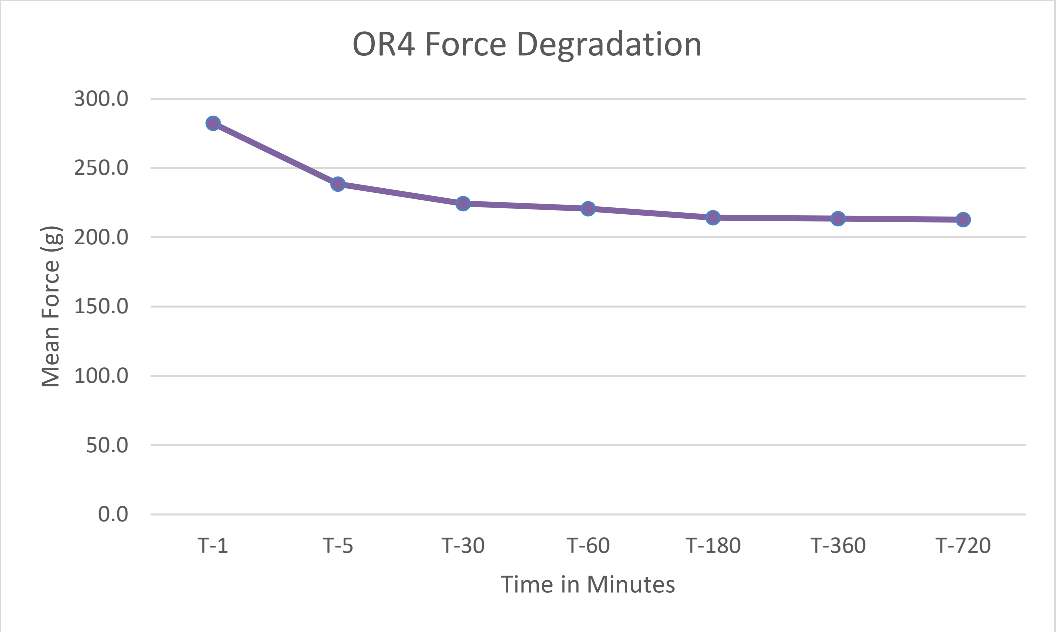
	323.6	275.9	256.6	252.3	251.3	249.3	245.5
	406.1	346.1	319.1	311.5	302.4	297.8	292.9
	311.3	266.1	247.5	243.3	239.7	237.9	234.1
AO5	174.6	144	135.1	131.5	128.6	128.8	128.8
	161.7	134.2	127.2	126.3	125.4	125.9	127.7
	179	147.9	137.9	135.1	133.2	133.2	133
	174.7	140.3	130.9	129.1	128.7	127.9	132.4
	159.2	135.7	128.1	127	127.1	127.5	127.6
	156.7	125.9	118	117.1	117.3	119.5	119.2
	164.1	127	120.7	119.1	116.6	115.5	116.7
	155.8	128	120.8	120	121.7	122.9	123.6
	181.9	142.2	130.8	127.2	124	122.8	122.4
	155	126.6	117.9	116.5	118.7	119	117
AO6	291.3	212.1	197.3	192.3	187.9	185.9	185.9
	242	177.7	165.1	161.3	157.9	157.6	158.8
	234.5	168.5	157.2	153.7	155.4	153.8	153.3
	273.3	196.8	182.5	176.8	173.5	170.5	171.5
	229.4	165.7	155	151.7	147.3	145.7	145.8
	236.1	171.2	161.4	158.7	156.6	155	155.8
	221.6	155.1	143.1	139.4	132.8	129.6	130.6
	236.1	168.5	156.7	153.6	150.1	148.9	151.5
	279	201	187.4	183.4	180.2	176.6	175.1
	274	195.2	183	180.2	176.9	177	175.7
	225.2	158.9	146.8	143.1	139.8	136.6	137.1
	226.3	161.3	150.2	147	146.6	145.6	145.7

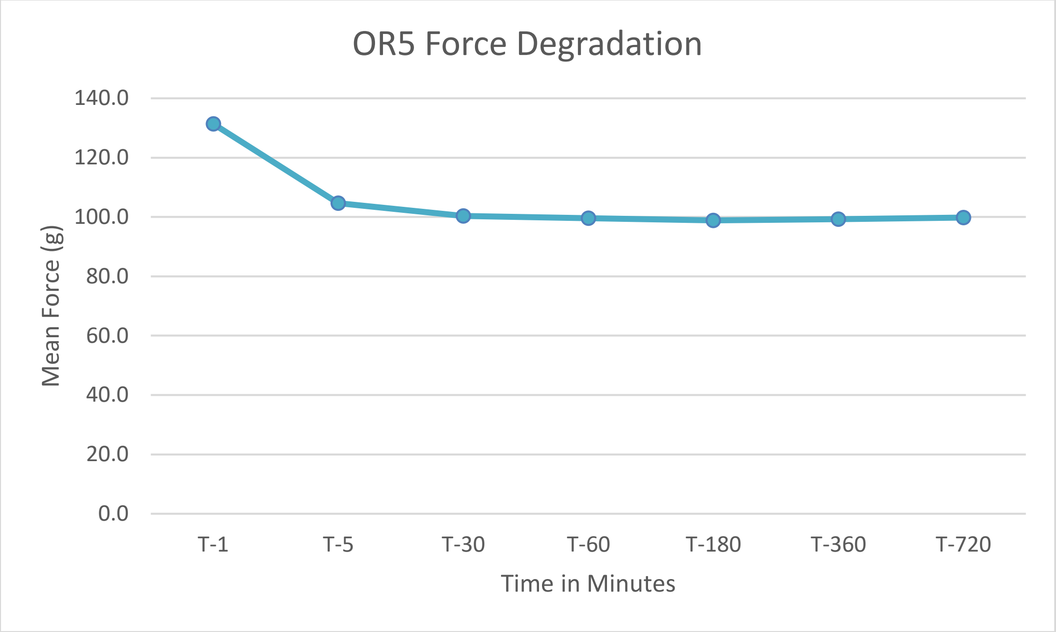
Appendix C: Elastic Mean Force Degradation for OR Groups

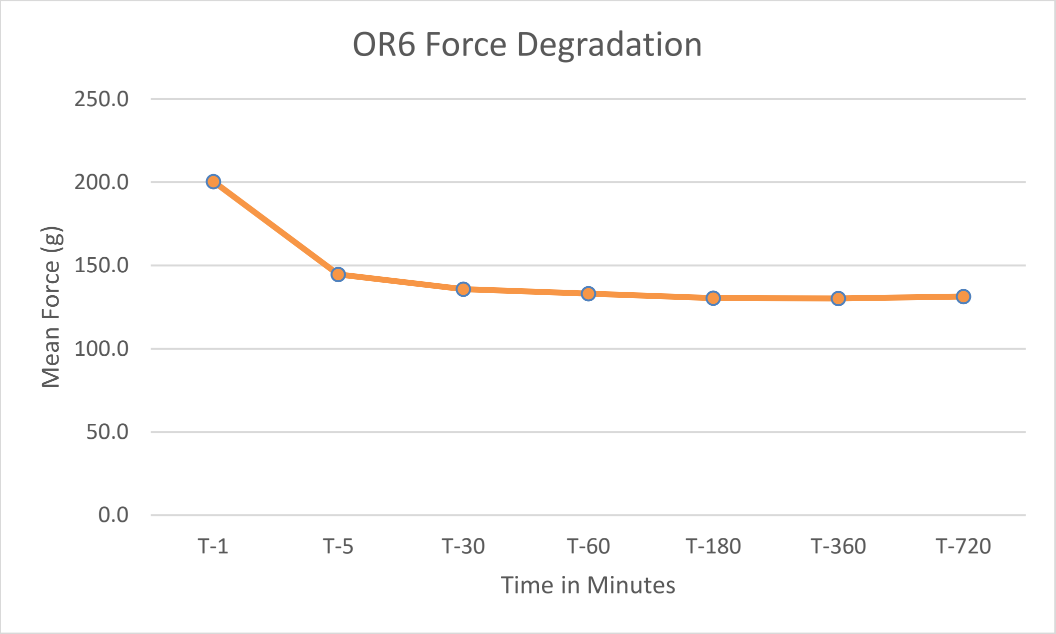




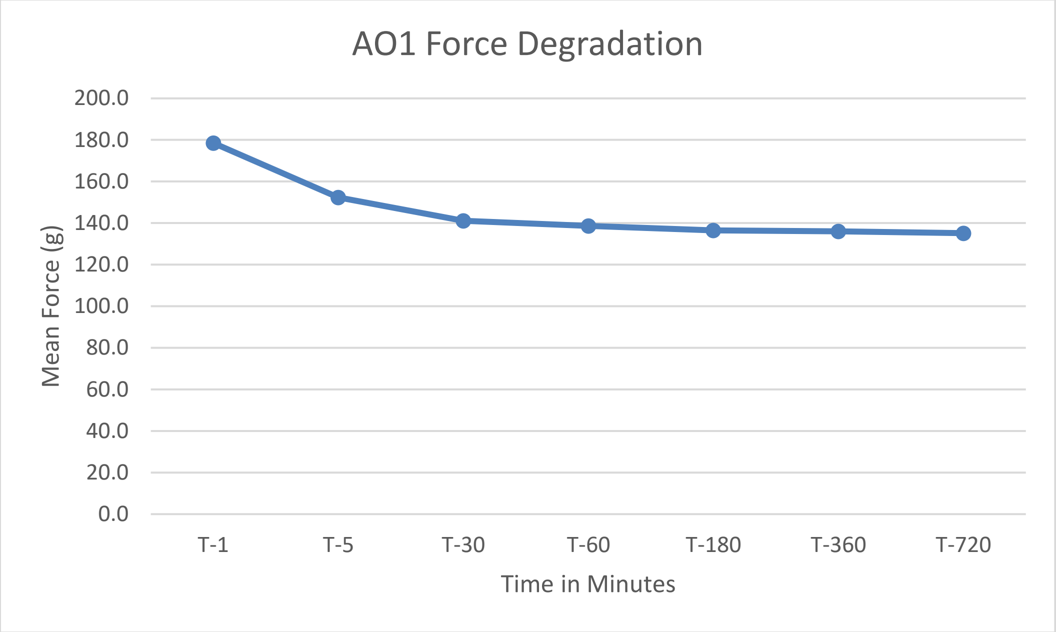

OR3 Force Degradation
Mean Force (g)
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
T-1
T-5
T-30
T-60
T-180
T-360
T-720
Time in Minutes

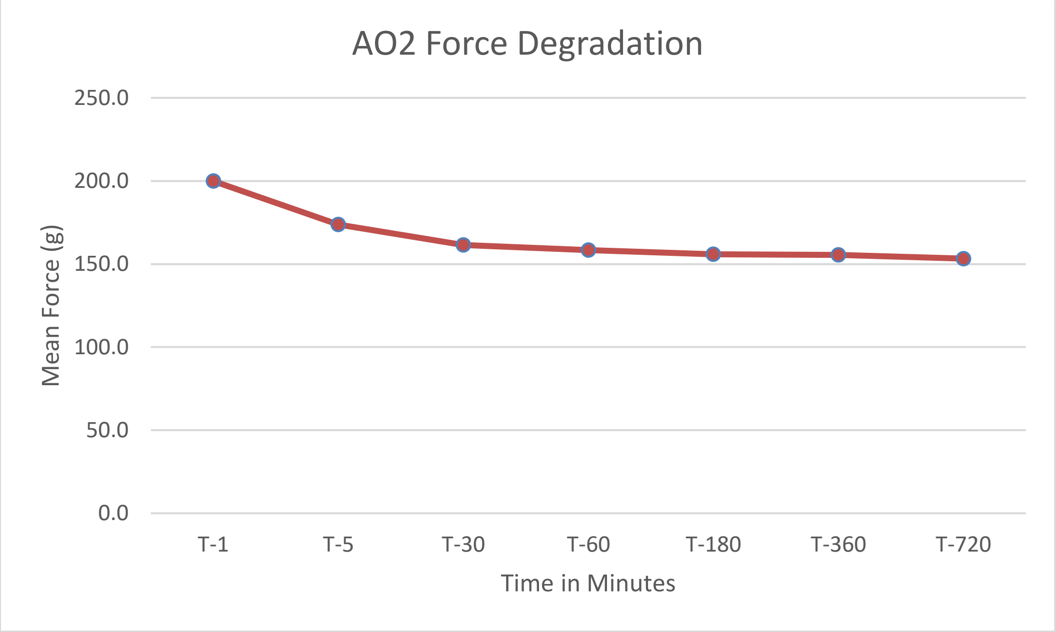

OR4 Force Degradation
Mean Force (g)
300.0
250.0
200.0
150.0
100.0
50.0
0.0
T-1
T-5
T-30
T-60
T-180
T-360
T-720
Time in Minutes

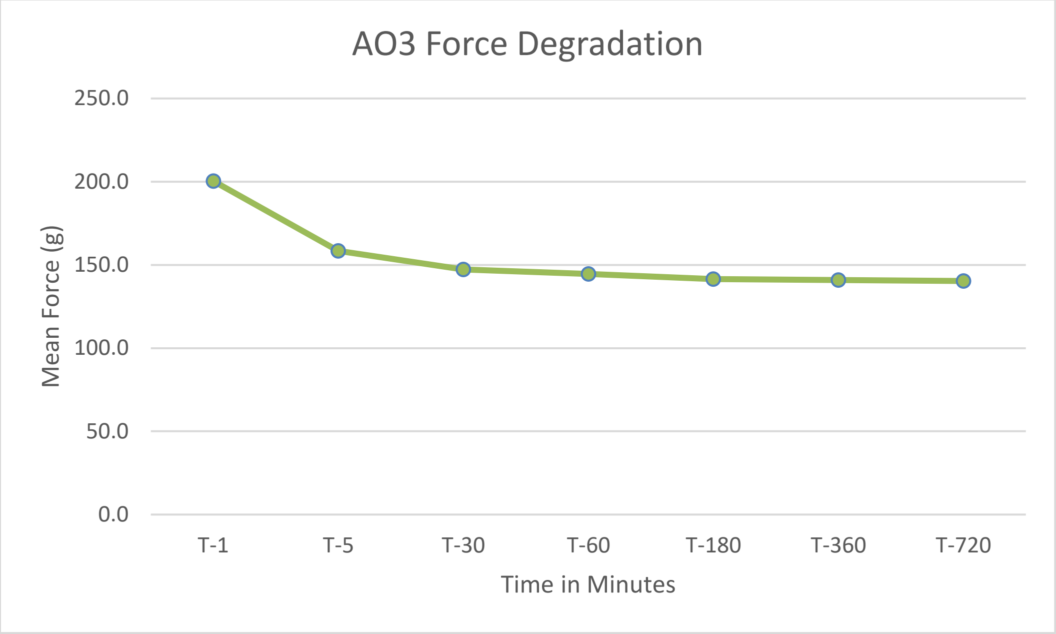

OR5 Force Degradation
Mean Force (g)
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
T-1
T-5
T-30
T-60
T-180
T-360
T-720
Time in Minutes

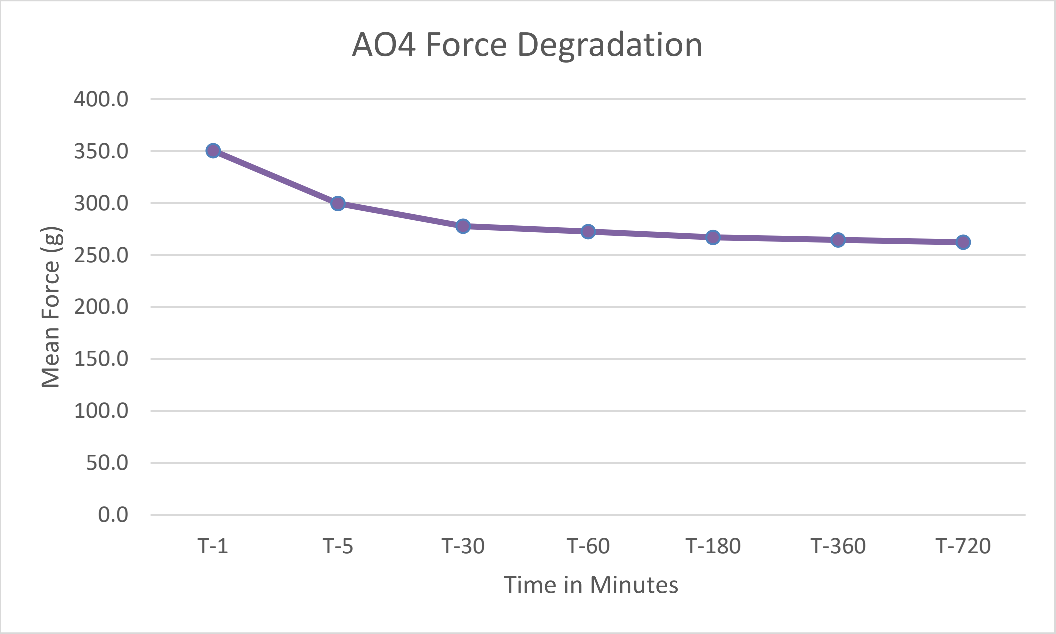

OR6 Force Degradation
Mean Force (g)
250.0
200.0
150.0
100.0
50.0
0.0
T-1
T-5
T-30
T-60
T-180
T-360
T-720
Time in Minutes

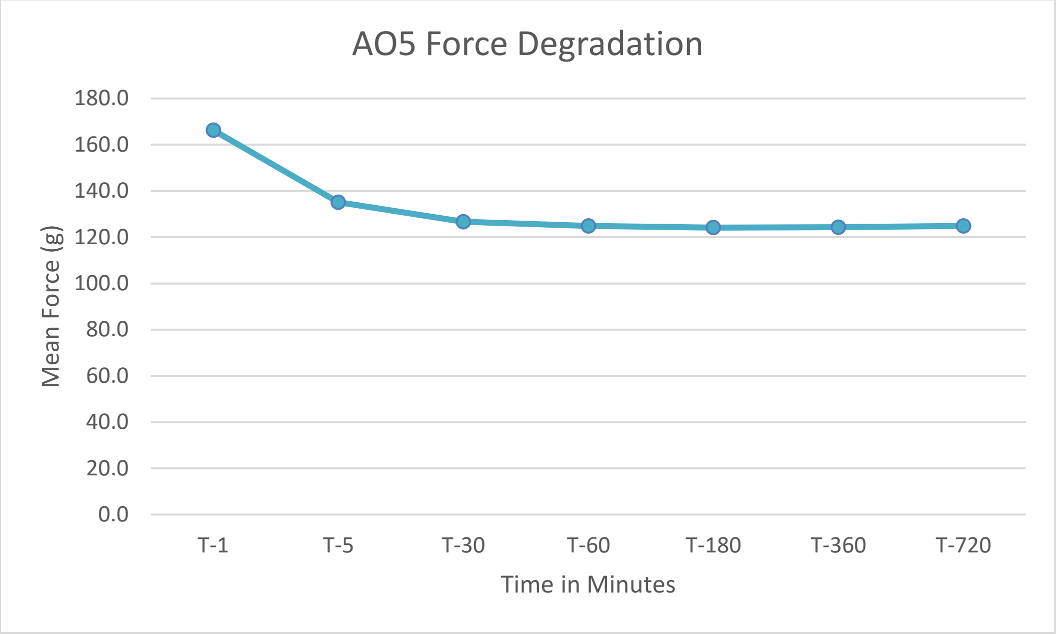
Appendix D: Elastic Mean Force Degradation for AO Groups

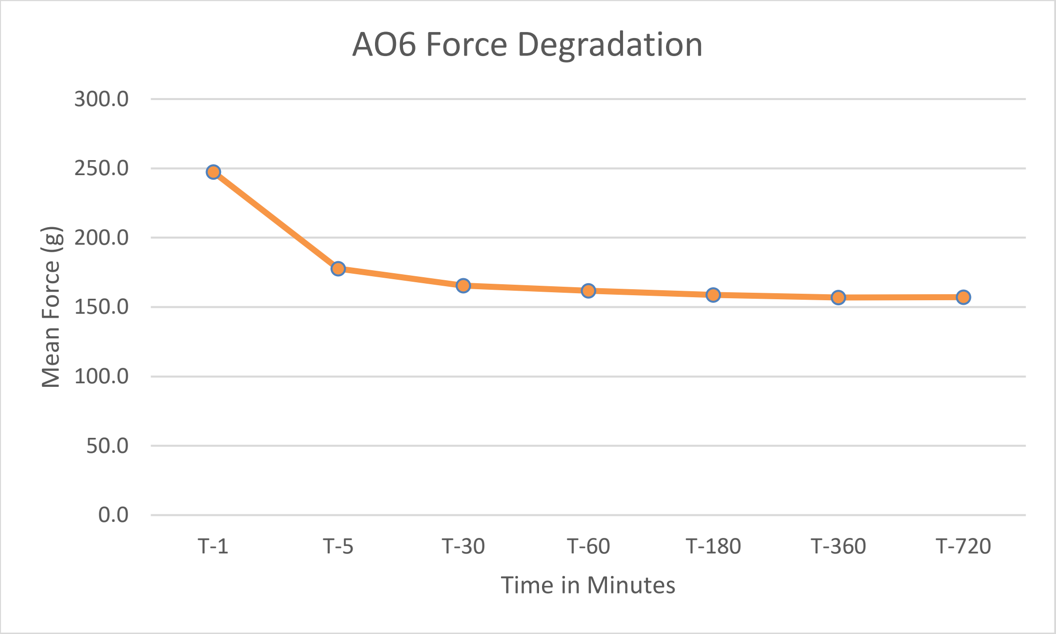





AO3 Force Degradation
Mean Force (g)
250.0
200.0
150.0
100.0
50.0
0.0
T-1
T-5
T-30
T-60
T-180
T-360
T-720
Time in Minutes


AO4 Force Degradation
Mean Force (g)
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
T-1
T-5
T-30
T-60
T-180
T-360
T-720
Time in Minutes


AO5 Force Degradation
Mean Force (g)
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
T-1
T-5
T-30
T-60
T-180
T-360
T-720
Time in Minutes


AO6 Force Degradation
Mean Force (g)
300.0
250.0
200.0
150.0
100.0
50.0
0.0
T-1
T-5
T-30
T-60
T-180
T-360
T-720
Time in Minutes

Appendix E: Tukey Multiple Comparison Test p-Values at Each Time Point for OR Elastic Groups

T-1						
	OR1	OR2	OR3	OR4	OR5	OR6
OR1		<.001	<.001	<.001	.117	<.001
OR2			<.001	<.001	<.001	.662
OR3				<.001	<.001	<.001
OR4					<.001	<.001
OR5						<.001
OR6						

T-5						
	OR1	OR2	OR3	OR4	OR5	OR6
OR1		<.001	.025	<.001	.001	<.001
OR2			<.001	<.001	<.001	<.001
OR3				<.001	<.001	.003
OR4					<.001	<.001
OR5						<.001
OR6						

T-30						
	OR1	OR2	OR3	OR4	OR5	OR6
OR1		<.001	.073	<.001	.006	<.001
OR2			<.001	<.001	<.001	<.001
OR3				<.001	<.001	.003
OR4					<.001	<.001
OR5						<.001
OR6						

T-60						
	OR1	OR2	OR3	OR4	OR5	OR6
OR1		<.001	.088	<.001	.017	<.001
OR2			<.001	<.001	<.001	<.001
OR3				<.001	<.001	.007
OR4					<.001	<.001
OR5						<.001
OR6						

T-180						
	OR1	OR2	OR3	OR4	OR5	OR6
OR1		<.001	.197	<.001	.046	<.001
OR2			<.001	<.001	<.001	<.001
OR3				<.001	<.001	.011
OR4					<.001	<.001
OR5						<.001
OR6						

T-360						
	OR1	OR2	OR3	OR4	OR5	OR6
OR1		<.001	.220	<.001	.057	<.001
OR2			<.001	<.001	<.001	<.001
OR3				<.001	<.001	.007
OR4					<.001	<.001
OR5						<.001
OR6						

T-720						
	OR1	OR2	OR3	OR4	OR5	OR6
OR1		<.001	.178	<.001	.050	<.001
OR2			<.001	<.001	<.001	<.001
OR3				<.001	<.001	.005
OR4					<.001	<.001
OR5						<.001
OR6						

Appendix F: Tukey Multiple Comparison Test p-Values at Each Time Point for AO Elastic Groups

T-1						
	AO1	**AO2**	**AO3**	**AO4**	**AO5**	**AO6**
AO1		.002	.278	<.001	.831	<.001
AO2			.428	<.001	<.001	.061
AO3				<.001	.017	<.001
AO4					<.001	<.001
AO5						<.001
AO6						

T-5						
	AO1	**AO2**	**AO3**	**AO4**	**AO5**	**AO6**
AO1		<.001	.977	<.001	.332	.030
AO2			.004	<.001	<.001	.562
AO3				<.001	.077	.180
AO4					<.001	<.001
AO5						<.001
AO6						

T-30						
	AO1	**AO2**	**AO3**	**AO4**	**AO5**	**AO6**
AO1		<.001	.966	<.001	.426	.020
AO2			.003	<.001	<.001	.567
AO3				<.001	.095	.152
AO4					<.001	<.001
AO5						<.001
AO6						

T-60						
	AO1	**AO2**	**AO3**	**AO4**	**AO5**	**AO6**
AO1		<.001	.968	<.001	.448	.023
AO2			.003	<.001	<.001	.511
AO3				<.001	.106	.169
AO4					<.001	<.001
AO5						<.001
AO6						

T-180						
	AO1	**AO2**	**AO3**	**AO4**	**AO5**	**AO6**
AO1		<.001	.982	<.001	.507	.022
AO2			.001	<.001	<.001	.444
AO3				<.001	.159	.133
AO4					<.001	<.001
AO5						<.001
AO6						

T-360						
	AO1	**AO2**	**AO3**	**AO4**	**AO5**	**AO6**
AO1		<.001	.984	<.001	.555	.036
AO2			.001	<.001	<.001	.318
AO3				<.001	.193	.183
AO4					<.001	<.001
AO5						<.001
AO6						

T-720						
	AO1	**AO2**	**AO3**	**AO4**	**AO5**	**AO6**
AO1		<.001	.977	<.001	.689	.022
AO2			.002	<.001	<.001	.553
AO3				<.001	.257	.142
AO4					<.001	<.001
AO5						<.001
AO6						

Appendix G: Time Point Pairwise Comparisons Test p-Values for OR Elastic Groups

OR1							
	T-1	**T-5**	**T-30**	**T-60**	**T-180**	**T-360**	**T-720**
T-1		<.001	<.001	<.001	<.001	<.001	<.001
T-5			<.001	<.001	<.001	<.001	<.001
T-30				<.001	<.001	.030	.091
T-60					.037	.754	1.000
T-180						1.000	1.000
T-360							1.000
T-720							

OR2							
	T-1	**T-5**	**T-30**	**T-60**	**T-180**	**T-360**	**T-720**
T-1		<.001	<.001	<.001	<.001	<.001	<.001
T-5			<.001	<.001	<.001	<.001	<.001
T-30				<.001	.008	.198	.040
T-60					.151	1.000	.335
T-180						1.000	1.000
T-360							1.000
T-720							

OR3							
	T-1	**T-5**	**T-30**	**T-60**	**T-180**	**T-360**	**T-720**
T-1		<.001	<.001	<.001	<.001	<.001	<.001
T-5			<.001	<.001	<.001	<.001	<.001
T-30				.004	<.001	<.001	<.001
T-60					.190	.012	.174
T-180						1.000	1.000
T-360							.830
T-720							

OR4							
	T-1	**T-5**	**T-30**	**T-60**	**T-180**	**T-360**	**T-720**
T-1		<.001	<.001	<.001	<.001	<.001	<.001
T-5			<.001	<.001	<.001	<.001	<.001
T-30				<.001	.009	<.001	<.001
T-60					.149	.016	.009
T-180						1.000	.559
T-360							.351
T-720							

OR5							
	T-1	**T-5**	**T-30**	**T-60**	**T-180**	**T-360**	**T-720**
T-1		<.001	<.001	<.001	<.001	<.001	<.001
T-5			.002	.008	.004	.023	.004
T-30				1.000	.251	1.000	1.000
T-60					.660	1.000	1.000
T-180						1.000	1.000
T-360							1.000
T-720							

OR6							
	T-1	**T-5**	**T-30**	**T-60**	**T-180**	**T-360**	**T-720**
T-1		<.001	<.001	<.001	<.001	<.001	<.001
T-5			<.001	<.001	<.001	<.001	<.001
T-30				<.001	<.001	<.001	.002
T-60					<.001	.038	.986
T-180						1.000	1.000
T-360							.080
T-720							

Appendix H: Time Point Pairwise Comparisons Test p-Values for AO Elastic Groups

AO1							
	T-1	T-5	T-30	T-60	T-180	T-360	T-720
T-1		<.001	<.001	<.001	<.001	<.001	<.001
T-5			<.001	<.001	<.001	<.001	<.001
T-30				<.001	<.001	.004	.003
T-60					.029	.345	.159
T-180						1.000	1.000
T-360							.707
T-720							

AO2							
	T-1	T-5	T-30	T-60	T-180	T-360	T-720
T-1		<.001	<.001	<.001	<.001	<.001	<.001
T-5			<.001	<.001	<.001	<.001	<.001
T-30				<.001	<.001	<.001	<.001
T-60					<.001	.009	<.001
T-180						1.000	.008
T-360							<.001
T-720							

AO3							
	T-1	T-5	T-30	T-60	T-180	T-360	T-720
T-1		<.001	<.001	<.001	<.001	<.001	<.001
T-5			<.001	<.001	<.001	<.001	<.001
T-30				<.001	<.001	<.001	<.001
T-60					.001	.004	.002
T-180						.330	.361
T-360							1.000
T-720							

AO4							
	T-1	**T-5**	**T-30**	**T-60**	**T-180**	**T-360**	**T-720**
T-1		<.001	<.001	<.001	<.001	<.001	<.001
T-5			<.001	<.001	<.001	<.001	<.001
T-30				<.001	<.001	<.001	<.001
T-60					.002	.001	<.001
T-180						.003	.016
T-360							.712
T-720							

AO5							
	T-1	**T-5**	**T-30**	**T-60**	**T-180**	**T-360**	**T-720**
T-1		<.001	<.001	<.001	<.001	<.001	<.001
T-5			<.001	<.001	<.001	<.001	.002
T-30				.010	.339	1.000	1.000
T-60					1.000	1.000	1.000
T-180						1.000	1.000
T-360							1.000
T-720							

AO6							
	T-1	**T-5**	**T-30**	**T-60**	**T-180**	**T-360**	**T-720**
T-1		<.001	<.001	<.001	<.001	<.001	<.001
T-5			<.001	<.001	<.001	<.001	<.001
T-30				<.001	<.001	<.001	<.001
T-60					.008	.001	.003
T-180						.005	.199
T-360							1.000
T-720							

Curriculum Vitae

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