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In vitro comparison of force decay between three orthodontic sliding retraction methods

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AN *IN VITRO* COMPARISON OF FORCE DECAY BETWEEN THREE ORTHODONTIC SLIDING RETRACTION METHODS

PAMELA STEIGER, D.M.D.

A Thesis Presented to the Faculty of the College of Dental Medicine of

Nova Southeastern University in Partial Fulfillment of the Requirements for the

Degree of

MASTER OF SCIENCE

December 2014

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By

PAMELA STEIGER, D.M.D.

A thesis submitted to the College of Dental Medicine of Nova Southeastern University in partial fulfillment of the requirements for the degree of

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

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DEDICATION

To my wonderful husband and family who have supported me to reach my goals.

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Abstract

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DEGREE DATE: DECEMBER 12, 2014

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Objective: The purpose of this *in vitro* study was to determine if there is a difference in force decay between three sliding retraction methods under a standardized force delivery system (200 gm at 25 mm stretch) at 2, 4, 6, and 8 weeks. **Background:** In order to achieve proper esthetics, occlusion and stability, orthodontic treatment may require extractions.[1, 2] Elastomeric chains, Nickel Titanium (NiTi) coils, and active ligatures are commonly used to close these extraction spaces.[2-4, 5] **Methods:** Twenty samples of each retraction method (elastomeric chains, NiTi Coils and active ligatures) were evaluated under standardized conditions (200 gm at 25 mm). The force of each retraction method was measured at 0, 2, 4, 6, and 8 weeks on a customized force gauge test stand (Shimpo FGV-1XY force gauge; *Shimpo Instruments,* Itasca, IL). Ten control samples were evaluated at 0 weeks and left un-stretched until the final measurement at 8 weeks. All samples were stored in a bath of Fusayama/Meyer artificial saliva (Pickering Laboratories, *Mountain View, California*) at 37°C in order to simulate the oral cavity.[6, 7] **Results:** At 2 weeks, the NiTi coils maintained their force while both the elastomeric chains and active ligatures experienced a statistically significant decrease in force over time. At 4, 6, and 8 weeks, the force of the elastomeric chains and active ligatures continued to decay and demonstrated a statistically significant decrease in force as compared to the NiTi coils and each other. At 8 weeks, the NiTi coils, elastomeric chains and active ligatures maintained 94.0%, 66.8% and 50.9%, respectively. This signifies a hierarchy of force decay with NiTi coils maintaining the largest amount of force, followed by the elastomeric chains and then the active ligatures. **Conclusion:** There is a significant difference in the amount of force decay of the three retraction methods over time under a standard initial force delivery of 200 gm over a 25 mm stretch. NiTi coils provide the light and constant force desired for efficient and biologically compatible tooth movement. The elastomeric chains maintained a larger amount of force than expected and have proven to achieve comparable tooth movement to NiTi coils in clinical studies. Active ligatures do not appear to be an effective means of force delivery. A force gauge is recommended to evaluate all forces placed clinically.

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Chapter 1: Introduction

1.1 Overview

1.1.1 Development of Modern Orthodontic Appliances

In the early twentieth century, Edward Hartley Angle was recognized as the “Father of Modern Orthodontics”.[1] After many years of clinical practice, Angle was inspired to develop a standardized appliance that would allow for “simplicity, stability, efficiency, delicacy and inconspicuousness”.[8] In the 1920’s, Angle’s ideas became known as the “Angle System” and he introduced an edgewise bracket system with a rectangular slot for orthodontic wire insertion. He provided orthodontists with a universal appliance system to treat patients consistently at a higher standard of care.[8] The use of rectangular archwires in horizontal rectangular bracket slots allowed for more accuracy and control of the root and crown position in all three dimensions, especially bucco-lingual torque.[1, 8] This edgewise appliance went on to become one of the greatest innovations in orthodontics and the prototype for modern orthodontic brackets.[1, 8]

With Angle acting as his mentor, Charles Tweed was the first to devote his practice to purely edgewise techniques.[8] Tweed spent the next two years actively treating patients with Angle’s guidance and technique. Shortly before his death, Angle asked Tweed to dedicate his life to the development of the edgewise appliance and to establish orthodontics as a specialty. It has been said that Angle provided orthodontics with the edgewise bracket, but it was Tweed who brought the appliance to the specialty and became the premier edgewise orthodontist of his time.[8] Tweed improved on Angle’s edgewise bracket system by bending the rectangular archwires in specific dimensions. These wire bends are categorized into three orders: first order bends in the bucco-lingual dimension, second order bends in the inciso-gingival dimension, and third order bends for bucco-lingual torque.[1]

In 1972, Larry Andrews introduced the “straight wire” appliance.[1, 8] His appliance incorporated first, second and third order bends (i.e. prescriptions) into the bracket slot and reduced the need for repetitive bends in the archwire that were necessary to compensate for differences in tooth anatomy and position.[1, 8] The use of bracket prescriptions increased the efficiency of orthodontic treatment as the details of final tooth positions were incorporated into the brackets themselves and the need for wire bending during clinical operations was minimized.[9] The advancement of bonding techniques further promoted the use of different brackets for each tooth and orthodontic suppliers began providing brackets with varying prescriptions.[1, 8, 9] Today, the orthodontist can specify which bracket prescription he or she would like to use, with the option of even creating a personalized prescription. Andrews’ modifications improved the efficiency of the edgewise appliance system to date and it has become known as the “pre-adjusted appliance”.[1, 9]

From a historical point of view of orthodontics, it is clear that our contemporary fixed appliances are the evolutionary products of Angle’s edgewise arch system.[8, 9] In addition to appliances, Edward Angle and his followers had a profound effect on the development of the specialty of Orthodontics. Inevitably, they had a large influence on treatment philosophy.

1.1.2 Extraction Debate

Edward Angle strongly opposed orthodontic extraction and paid little attention to facial proportions and esthetics. He believed that the best esthetics were achieved when the patient had ideal occlusion.[1] After Angle's death, Tweed initially carried on Angle's conviction that teeth must never be extracted. Four years later, Tweed re-evaluated the outcomes of his cases and decided that he was not pleased with the facial balance. He re-treated these cases with four premolar extractions and compared the two final outcomes only to find that the extraction final result was far superior. Tweed then became an advocate of four premolar extractions for facial esthetics. His work revolutionized the field in the 1940's and 1950's as it now became acceptable to extract teeth for orthodontic correction.[1, 8] In 1989, a survey of 238 orthodontists in Michigan was conducted to evaluate the prevalence of orthodontic extractions and found the mean rate of extraction treatment to be 39%. The rate of extraction varied greatly between orthodontists.[10]

On a daily basis, orthodontic patients present with malocclusions and/or facial imbalance. Often times, teeth must be extracted in order to obtain proper esthetics, occlusion, and stability. Extraction of teeth can improve the facial esthetics of a patient with procumbent or protrusive lips.[1] This can be accomplished by retracting the anterior teeth into the extraction spaces, thus retracting the lips to a more balanced position. Teeth can also be removed in a strategic manner in order to correct for a Class II or Class III malocclusion.[1] In a patient that presents with a Class II dental malocclusion, for example, the maxillary molar is mesially positioned relative to the mandibular first molar. Strategically, maxillary first premolars can be extracted with or without mandibular second premolar extraction to move the maxillary dentition distally or mandibular dentition mesially to achieve the proper Class I occlusion. In a Class III patient, the maxillary dentition is distally positioned relative to the mandibular first molar. Extractions of mandibular first premolars with or without extractions of maxillary first premolars may be selected. Finally, teeth may be extracted to provide better post-treatment stability of the dentition.[1] Tweed advocated for uprighting of the mandibular incisors over the basal bone and determined that this was the most stable position.[1] In many cases, teeth must be extracted in order to create space for this incisor uprighting.

In summary, teeth may be extracted in order to achieve proper esthetics, occlusion, and stability. Moving the remaining teeth strategically into the extraction spaces becomes an essential part of orthodontic treatment.

1.1.3 Orthodontic Space Closure

Orthodontic treatment with extractions has been gaining popularity in an effort to produce a proper occlusion with more stable and esthetic outcomes. Accordingly, premolars are often considered for extraction with subsequent space closure by retraction of neighboring teeth into the extraction spaces. In clinic, various methods of space closure have been developed.

One of the most common methods of space closure is “sliding retraction”.[2, 3, 11] Sliding retraction involves a Class I (intra-arch) mechanism with an appropriate method of force application and delivery.[3] For example, in the case of first premolar extraction, the canine tooth can be moved posteriorly into the extraction space by sliding it along a stiff archwire. Once the canine tooth is in the desired position, the anterior segment of incisors can now be retracted and the excess wire will slide out the back of the molar tubes.[2] Ultimately, a force must be placed to overcome the inherent resistance to wire sliding (i.e. friction & binding) in the bracket system and to move the teeth along the wire.[1, 12]

1.1.4 Resistance in Sliding Mechanics

In sliding mechanics, tooth movement is the result of a net force applied to the teeth after the deduction of friction and binding effects from the total force applied.[8] Friction occurs at the interface of two objects as they move past one another and produces a resistance to the movement desired.[13, 14] In orthodontic tooth movement, friction is present when the wire makes contact with the walls or bottom of the bracket base as the tooth is moved along the wire.[1, 14] Another phenomenon called binding occurs as the tooth tips during tooth movement and the wire contacts the corners of the bracket.[1] The combination of friction and binding contributes to the resistance to sliding.[1]

In the case of sliding retraction, forces anywhere between 100 to 200 gm have been recommended. [4, 6, 15-19] One study showed that friction caused a 60-80% loss in orthodontic force during canine retraction via sliding mechanics.[12] A follow-up study revealed that 25% of the applied force was lost during anterior segment retraction en-masse.[20] As a result, a two-fold increase in force has been advocated in order to overcome the sliding resistance.[14] To retract a canine with sliding mechanics, a force of 100 gm is necessary for tooth movement and an additional force of 100 gm is needed to overcome the resistance effects of binding and friction.[1] Accordingly, a force of 200 gm was applied in this study.

1.1.5 Desirable Forces

Research has shown that light and constant forces provide an optimal force system to move teeth in a biologically compatible manner without adverse side effects.[7, 16, 19, 21-23] Orthodontic tooth movement requires the application of a sustained force that must be present for a certain amount of time.[1] More effective tooth movement can be produced if the force is maintained over a longer duration.[1]

A continuous force is defined as a force that is maintained between visits; an interrupted force declines to zero between activations.[1] Depending on the forces applied, different kinds of resorption may occur in the area of desired tooth movement. The use of heavy forces causes necrosis of adjacent tissues and undermining resorption occurs with zones of hyalinization; this may result in a delay of tooth movement.[1, 22, 24] If a light, continuous force is applied, a relatively smooth sequence of tooth movement will transpire as a favorable mode of frontal resorption occurs.[1, 19, 22, 24]

In clinical practice, a four to six week appointment interval is common.[1, 25] If the appliance can apply light forces continuously and produce only frontal resorption, no further activation is needed. Frequent activations of an appliance does not allow for an appropriate repair process to occur and can lead to tooth damage that could have been prevented or minimized with less frequent activations.[1, 25]

Ultimately, it is imperative for orthodontists to find a method that can deliver a force with the least amount of decay in this force over time. This will allow the orthodontist to treat patients in an efficient and biologically compatible manner.[7, 25, 26] To provide this force system, one must thoroughly understand the materials and methods available to the orthodontist.

1.1.6 Stress-Strain Curve

The elastic behavior of any material is defined by its response to an external load as demonstrated by a stress-strain curve.[1] Stress is defined as the force per unit area and describes the internal distribution of the load.[1, 16] Strain refers to the deflection per unit length and describes the internal distortion produced by this load.[1, 16] Clinical usefulness of any orthodontic material can be determined by evaluating this stress-strain curve.[1] The highest point at which the stress and strain still display a linear relationship is termed the “proportional limit.” Beyond this point, the material reaches its “elastic limit” and can only sustain a small amount of additional force before permanent deformation occurs.[1] In orthodontics, we want to avoid this permanent deformation and desire to use materials that behave elastically – specifically, the stress increases proportionally to the strain within the elastic limit.[11]

1.2 Methods of Sliding Retraction

In orthodontic practice, there are three common methods of sliding retraction: elastomeric chains, active ligatures, and Nickel Titanium (NiTi) coils.[4, 6, 11] It has been discussed that the potential disadvantage of elastic chain and active ligatures is their propensity for a large amount of force decay over time.

Alternatively, NiTi coil springs have become more popular as their forces remain fairly constant.[4, 18, 23] Even with the previous research completed on these different materials, the search for the most effective and efficient method continues.[6, 7, 18]

1.2.1 Elastomeric Chain

Elastomeric chain was introduced in the 1960's and has remained the traditional method of retraction and general space closure.[27-29] Elastomeric chain is commonly tied from a posterior tooth (usually the molar hook) to the selected anterior tooth or hook to aid in obtaining the desired tooth movement.[4, 28] Although there are a few different ways to attach the elastomeric chain, a study comparing the different schemes showed that a direct attachment from the molar hook to the canine bracket or anterior hook is the most efficient.[28]

Elastomeric chain is relatively inexpensive, easy to use, and can be applied in a variety of clinical situations.[2, 6] However, it must be replaced every 4-6 weeks due to plaque retention/hygiene concerns and anticipated force decay.[1, 4, 11, 30, 31] The force from the elastomeric chain decays rapidly during the first 24 hours and then continues to decay after that until the patient's next appointment.[6, 29, 32, 33] According to this information, elastomerics may be better described as an intermittent or interrupted force rather than the preferred continuous force.[1, 34]

When exposed to the oral cavity, the elastomeric chains absorb the saliva, become stained and permanently deform as the internal bonds break down.[1, 27, 29, 31, 35] This exposure to saliva and oral temperatures may contribute to the inability of the elastomeric chain to sustain a continuous force level over an extended period of time.[30, 32, 36] Thus, the continuity of force over time of elastomeric chain remains in question.

Furthermore, the fabrication or composition of elastomeric chain can affect its force delivery. Samples of clear elastomeric chain have demonstrated more force remaining at a defined time point as compared to the colored elastomeric chain.[37] The elastomeric chain fabricated by Rocky Mountain Orthodontics known as “Energy Chain” has also been found to have the least amount of decay in force over time.[37] Accordingly, this study used clear Rocky Mountain “Energy Chain” (*Rocky Mountain Orthodontics*, Denver, CO; Closed, clear).

1.2.2 Active Ligatures

Small elastomeric modules or ligatures can also be used to close extraction spaces.[1] An active ligature is assembled by placing a stainless steel ligature through an elastomeric module. The elastomeric module is then attached to the molar hook and the steel ligature tie is attached to the anterior hook at a desired stretch to deliver an appropriate force.[2-4] This method is simple, economical and reliable; as such, they can be used routinely with few complications.[2] The actual force exerted by the ligature is a result of the initial force applied, the duration of application, and the rate of force decay of the ligature over time.[30, 37]

The investigation of active ligatures in the literature is not as extensive as elastomeric chains and NiTi coils. However, its physical properties remain similar to that of elastomeric chains and they must be replaced at each visit.[4, 30] The mean percentage of force decay in the elastomeric module was 53 to 68% within the first 24 hours.[30] Current manufacturers have tried to overcome these stated deficiencies by modifying their material composition and enhancing continuity of force delivery.[31] The elastomeric modules supplied from GAC have been shown to have the least amount of force decay.[30, 37] As a result, clear elastomeric modules supplied by GAC were used in this study (*Dentsply GAC International*, Islandia, NY; clear sani-ties).

1.2.3 Nickel Titanium Coils

Nickel titanium (NiTi) was introduced to the practice of Orthodontics in 1971 and has gained considerable popularity.[21, 38, 39] NiTi alloys are unique in that they are able to transition between two different phases – martensitic and austenitic. The martensitic phase is more stable at lower temperatures and higher stress levels; the austenitic phase is more stable at high temperatures and lower stress levels.[1] This phase transition capability allows for shape memory and superelasticity – properties not found in any other dental materials.[1, 24, 40]

“Shape memory” allows the material to remember its original shape after being plastically deformed in the martensitic phase/form and enables the material to return to its original form after force delivery.[1, 40-42] “Superelasticity” allows the material to undergo a reversible change in the internal structure after a defined amount of deformation, ultimately producing fairly constant force values when being deflected over small or large distances.[1, 40-42] This allows the NiTi alloy to deliver light continuous forces over a long range of activation.[8, 21, 39]

NiTi coils can be stretched from one hook to another or extended with a stainless steel ligature.[11] In several *in vivo* studies, NiTi coils have been shown to provide a more rapid and reliable amount of space closure.[4, 6, 18] This is theoretically due to their ability to retain more constant force over a given time period.[6, 21, 43] NiTi coils are more expensive but can be efficiently re-activated at each appointment.[4, 11, 39-42]

A great expanse of research has gone into the study of NiTi coils and their properties. Many of the studies have found that GAC Sentalloy coils deliver the most consistent amount of force over time.[42, 44] Overall, GAC Sentalloy NiTi closed coils have been the most widely tested.[4, 18, 39, 42-44] As such, NiTi coil springs from this manufacturer were chosen for this study (*Dentsply GAC International*, Islandia, NY; 9mm - heavy).

1.3 Research Process

1.3.1 Oral Environment Simulation

Previous *in vitro* investigations have shown that temperature and saliva have an effect on the dimensional stability of all three of the materials being tested.[29, 30, 32, 36, 41, 43] Elastomeric chains exposed to an *in vitro* environment exhibit a significant increase in the amount of force decay as compared to those samples stored in air or water.[36, 45] Performing an experiment in dry air at room temperature does not reflect the conditions that the materials are exposed to intraorally.[32] For that reason, all samples need to be stored inside a bath of artificial saliva at 37°C in order to most accurately simulate the oral cavity and provide for a baseline comparison.[6, 7, 23, 28] The artificial saliva should closely resemble natural saliva in its effect on the materials being studied, thereby meeting the requirements of creating an artificial oral environment.[46]

The synthetic saliva proposed by Fusayama *et al* most closely resembles natural saliva. Although there are other saliva “substitutes”, such as Biotene Dry Mouth Mouthwash (*GlaxoSmithKline*, United Kingdom) and “Oasis” (*Gebauer Consumer Healthcare,* Cleveland, OH), Fusayama Artificial Saliva remains the standard artificial saliva for use in biomaterials studies.[7, 47-49] Accordingly, Fusayama Artificial Saliva (Pickering Laboratories, *Mountain View, California*) was used in this study.

1.3.2 Application of Forces

Aside from the differences in actual methods of space closure, each orthodontist is unique in his or her application of force. Each individual generally applies consistent forces; however, the amount of force applied varies largely between orthodontists.[33] Some practitioners prefer to over-activate the elastomeric chain in order to provide a larger force to surmount the substantial force decay over time.[29, 50] This over-activation may actually contribute to the large amount of force decay found.[4] Additionally, the initial activation range of NiTi coils can alter their delivery of force.[7, 37, 41] Thus, it is important to ascertain a standardized amount of force delivery over a defined range in order to achieve the desired effects.

1.3.3 Measurement of Forces

Precision and accuracy of force measurements are important in assessing force decay. The Shimpo FGV-1XY (*Shimpo Instruments,* Itasca, IL) is a force gauge that offers strict tolerances and high accuracy. This model is able to record measurements to 0.1 gm resolution. This will allow for the utmost accuracy and reproducibility of force delivery and residual force measurements.

1.4 Importance of Study

All three of these sliding retraction methods are used in orthodontic practice on a daily basis. However, the force decay of all three methods under standardized *in vitro* conditions was still unknown. This study applied 200 gm of force as 100 gm is needed for tooth movement and an additional 100 gm is needed to overcome the effects of binding and friction when retracting teeth on an archwire.[1, 4] It has also been noted that the average distance between the midpoint of a first molar and canine bracket prior to space closure is approximately 25 mm.[28] Accordingly, the appropriate stretch/activation of each material was determined to achieve approximately 200 gm of force over this 25 mm span that is commonly encountered during space closure using sliding mechanics.[28,32]

This project is also unique in that it measured the force decay over a period of 2, 4, 6, and 8 weeks. Patients often have appointments set at 4, 6 or 8 week intervals.[25] Additionally, the sliding retraction material may be in place for a longer period of time if the patient does not show up for the scheduled orthodontic appointment.[11] It was important to assess the amount of force remaining at each time period to determine the appropriate appointment interval for each retraction method.

In this experiment, we were able to objectively determine whether or not there is a significant difference in the amount of force decay between the three methods at four different time intervals. If there was a significant difference, we can discriminate between them to determine which provides the most biologically compatible forces and least amount of force decay over time. If there is no significant difference, then any of the methods may be employed. The method or methods that offer a constancy of force over the six or eight week period may be beneficial to the orthodontist as patients can be seen at six or eight week appointment intervals. This is significant as it reduces chair time for the orthodontist and time missed from work or school for the patient. Oppositely, if the method chosen does not maintain the force over time, more frequent visits are necessary in order to obtain the desired tooth movement. The results will ultimately allow the orthodontist to make efficient and cost-effective decisions.[4, 7]

1.5 Purpose, Specific Aims and Hypotheses

1.5.1 Purpose

The purpose of this *in vitro* study was to determine if there is a difference force decay between three sliding retraction methods under a standard force delivery system (200 gm at 25 mm stretch) at 2, 4, 6, and 8 weeks. The results of this study will provide the orthodontist with a guide to determine which method of sliding retraction produces the most desirable light and continuous forces for optimal orthodontic tooth movement over various time intervals.

1.5.2 Specific Aims

1. To determine the proper stretch of each material in order to deliver a standardized force of 200 gm over 25 mm.
2. To compare the force decay between three orthodontic sliding retraction methods over a 2, 4, 6, and 8 week period.

1.5.3 Hypotheses

H_o:

1. There is no difference in the amount of initial force delivered between three orthodontic sliding retraction methods.
2. There is no difference in the amount of force decay between three orthodontic sliding retraction methods.

Chapter 2: Materials and Methods

2.1 Study

In this study, there were three different sample groups (See Figure 1): elastomeric chains (*Rocky Mountain Orthodontics*, Denver, CO; Closed, clear), active ligatures (*Dentsply GAC International*, Islandia, NY; clear Sani-Ties) and NiTi coils *(Dentsply GAC International*, Islandia, NY; Closed Heavy 200 gm). These materials were selected because they demonstrated the least amount of force decay in previous studies.[30, 37, 39, 43]

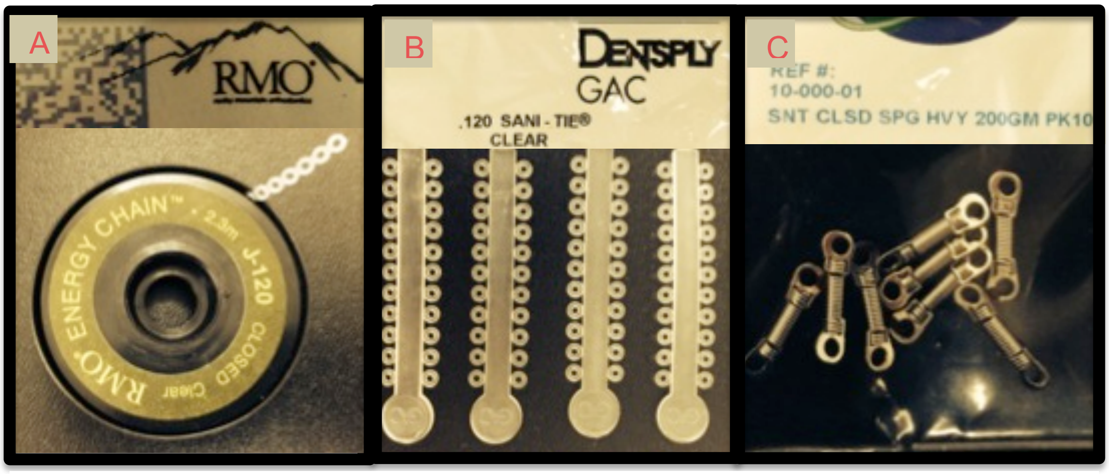

Figure 1. Retraction materials. A. Elastomeric chain, B. Active ligatures, C. NiTi coils

2.1.1. Ethical Issues

No potential ethical issues could be identified.

2.1.2. Grant

This study was funded through a grant from the Health Professions Division at Nova Southeastern University.

2.2. Sample Size Estimate

Each sample group consisted of both an experimental and control group. A power analysis was completed on a study performed by Taloumis *et al* that compared the force decay of active ligatures.[30] With an α=0.05, power of 80% and a standardized effect size of 0.85, the appropriate experimental sample size was determined to be 20 per group. The control group consisted of 10 samples per group, for a total of 30 samples for each method and 90 samples in total (see Figure 2).

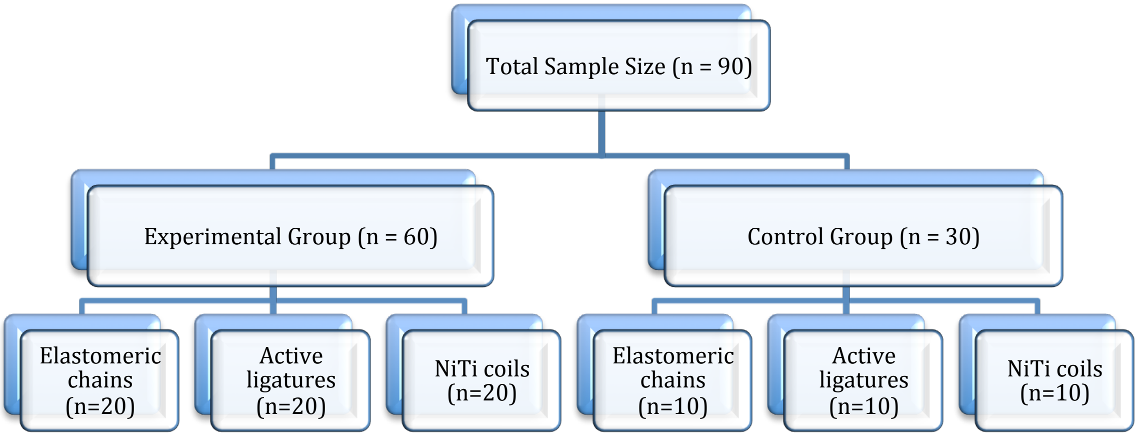

Figure 2. Sample distribution

2.3 Sample Preparation

In order to provide standardized conditions, the researcher first identified the proper stretch/length of each material to deliver a desired force of 200 gm over a 25 mm distance. A customized test stand was fabricated by anchoring a Shimpo FGV-1XY (*Shimpo Instruments,* Itasca, IL) hand force gauge to an acrylic plate. Two parallel stainless steel pins (diameter of 0.036 inches) were placed 35 mm apart – one in the measuring tip and the other in an opposing acrylic plate. A distance of 35 mm was chosen to account for the 5 mm length of each hook attached to the materials. Thus, the material itself was stretched over a 25 mm distance as displayed in Figure 3.

Figure 3. Shimpo force gauge test stand with fixed distance of 25 mm

The active ligatures and NiTi coils were attached to a stainless steel ligature and could be activated to the desired force delivery by twisting the ligature appropriately. Thus, it was not necessary to determine the length of materials needed.

After testing varying numbers of links of elastomeric chain at the fixed distance of 25 mm, it was determined that 7 links provides approximately 200 gm of force as desired. This is illustrated in Figure 4. As a result, 7 links of the elastomeric chain were used to fabricate each sample.

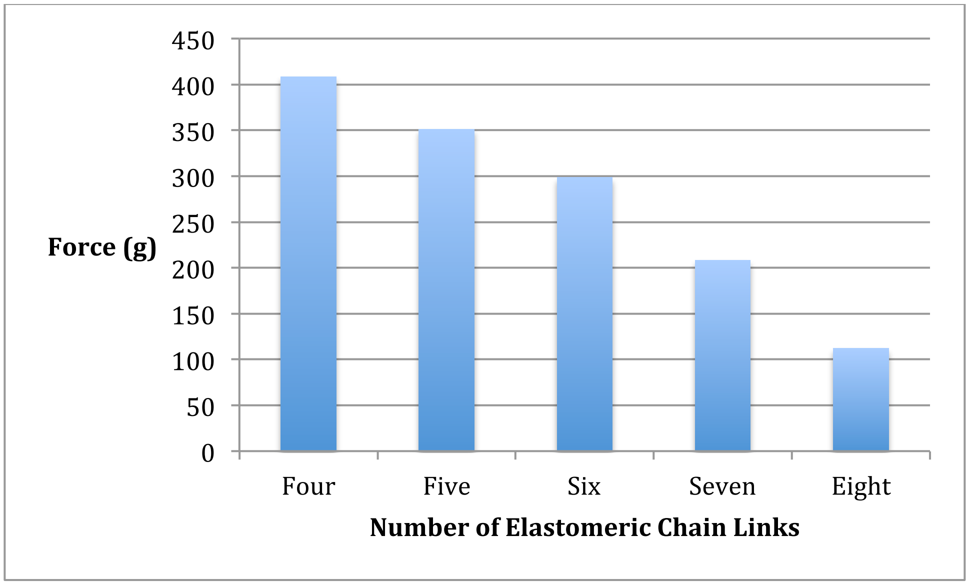

Figure 4. Force produced with different numbers of elastomeric chain links

Each sample was attached to a 5 mm stainless steel hook on each end. The hooks were placed over vertical stainless steel pins (0.036 inches in diameter) that were inserted an acrylic tray at a set distance of 35 mm (25 mm stretch plus 10 mm of hooks). In total, there were 60 sets of parallel pins to accommodate all samples (See Figure 5). This fixed distance also incorporated the desired force (200 gm).

Figure 5. Experimental group laboratory set-up

A control set-up was fabricated on a second acrylic tray with one vertical stainless steel pin per sample (See Figure 6).

Figure 6. Control group laboratory set-up

2.4 Experiment

The initial force in grams of each sample was measured and recorded by placing the attachment hook over the vertical pins as demonstrated in Figure 7.

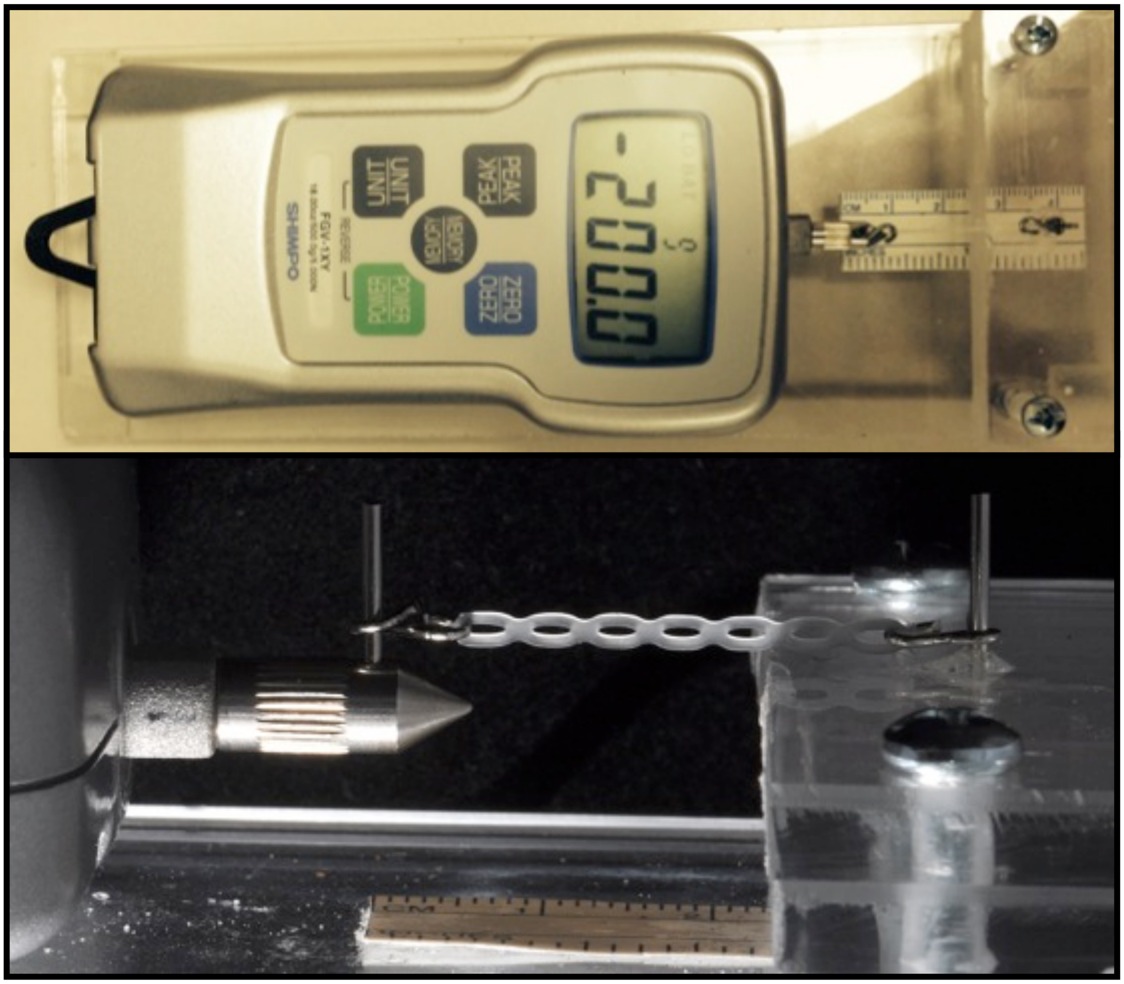

Figure 7. Measurement of force with Shimpo force gauge

Each experimental sample was then attached to the corresponding pins at the initial desired stretch and force delivery (see Figures 8-12).

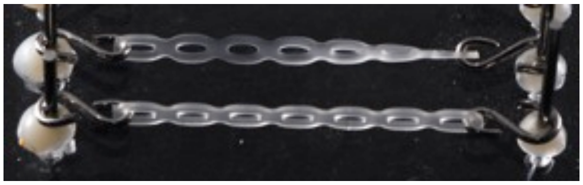

Figure 8. Elastomeric chain samples

Figure 9. Active ligature samples

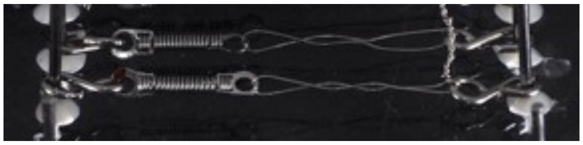

Figure 10. Nickel Titanium coil samples

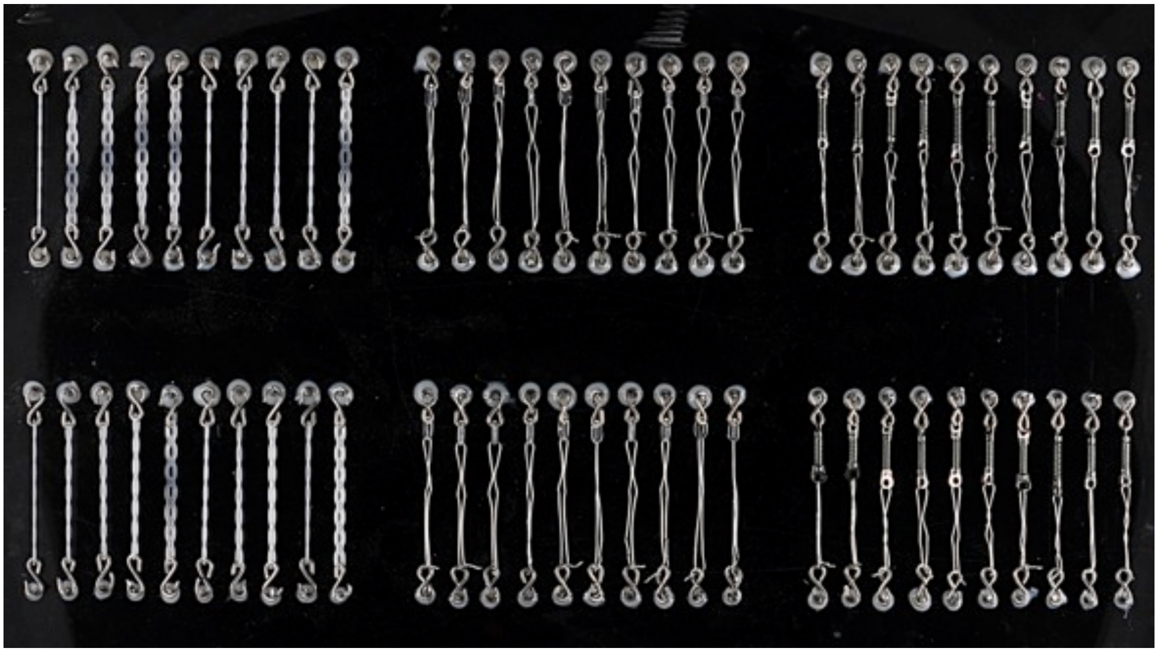

Figure 11. All samples stretched to 25 mm between pins

The force of the control group samples (see Figure 12) was measured at the initial time point. The samples were attached to a single vertical pin and left un-touched until the final force measurement at 8 weeks.

Figure 12. Control group samples

All samples were stored in Fusayama/Meyer artificial saliva (Pickering Laboratories, *Mountain View, California*) at 37°C. The force of the experimental samples was then re-measured at 2, 4, 6, and 8 weeks. At each time interval, the samples were transferred onto the test stand for measurement.

Figure 13. Oral environment simulation

At the end of the 2, 4, 6 and 8 week periods, the total force remaining for each sample was determined. An accurate assessment and comparison of force decay between the three methods/materials was then made.

2.5. Data Storage

The data was imported automatically into an excel spreadsheet and stored.

2.6. Statistical Analysis

For each group time interval measurement, the mean (with standard deviation), median (with range) and distribution of forces were calculated. Mean force differences from initial to final measurements were compared with paired *t*-tests. A one-way analysis of variance (ANOVA) (α=0.05) was performed to determine if there were any significant differences between the means of the force measurements after each time interval. A post-hoc Bonferroni analysis (α=0.05) was used to identify the differences between groups.

Chapter 3: Results

3.1. Standardization of Initial Force Delivery of Three Retraction Methods

In order to evaluate the force decay of all three retraction methods under standardized conditions, the initial force delivery of 200 gm at a distance of 25mm was confirmed (Table 1). The ANOVA results (α=0.05) failed to reject the first null hypothesis that there is no difference between three retraction methods in experimental and control groups (Table 2). Therefore, all of the groups were the same at Week 0.

Table 1. Force delivery of three retraction methods at Week 0 (Baseline).

Group	N	Mean	Median	SD	Min	Max
AL Control 0 Weeks	10	204.73	204.35	4.69	198.10	212.50
AL Experimental 0 Weeks	20	204.79	201.35	14.57	170.40	228.00
EC Control 0 Weeks	10	202.77	202.50	3.81	195.70	208.10
EC Experimental 0 Weeks	20	202.69	204.05	7.09	186.60	212.80
NC Control 0 Weeks	10	202.03	203.35	6.46	193.60	209.60
NC Experimental 0 Weeks	20	202.47	201.30	4.84	194.20	213.60

AL = Active Ligature; EC = Elastomeric Chain; NC = NiTi Coil

Table 2. Mean comparisons of force delivery - Week 0 (Baseline).

Week 0			Diff	Lower 95% CI	Upper 95% CI	P-Value
AL Experimental	vs	AL Control	0.06	-9.99	10.11	1.000
EC Experimental	vs	AL Control	-2.04	-12.09	8.01	1.000
NC Control	vs	AL Control	-2.70	-14.30	8.90	1.000
NC Experimental	vs	AL Control	-2.26	-12.39	7.88	1.000
EC Control	vs	AL Control	-1.96	-13.56	9.64	1.000
EC Experimental	vs	AL Experimental	-2.10	-10.31	6.11	1.000
NC Control	vs	AL Experimental	-2.76	-12.81	7.29	1.000
NC Experimental	vs	AL Experimental	-2.32	-10.63	6.00	1.000
EC Control	vs	AL Experimental	-2.02	-12.07	8.03	1.000
NC Control	vs	EC Experimental	-0.66	-10.71	9.39	1.000
NC Experimental	vs	EC Experimental	-0.22	-8.53	8.10	1.000
EC Control	vs	EC Experimental	0.08	-9.97	10.13	1.000
NC Experimental	vs	NC Control	0.44	-9.69	10.58	1.000
EC Control	vs	NC Control	0.74	-10.86	12.34	1.000
EC Control	vs	NC Experimental	0.29	-9.84	10.43	1.000

3.2. Force Decay of Retraction Methods

3.2.1 Force Decay of Active Ligatures

Active ligatures showed a statistically significant force decay starting at week 2 (Tables 3 and 4). At week 2, 59.9% of the initial force was remaining. This force decay continued throughout week 4 (58.7% remaining), week 6 (56.1% remaining), and week 8 (50.9% remaining). Between week 0 and week 2, the most significant force decay was noted. The incremental force loss that occurred between week 2, 4, 6 and 8 was not significant. A significant difference was noted, however, between the amount of force present at week 8 vs. week 2.

Table 3. Force delivery of active ligatures (AL) at Week 0, 2, 4, 6, and 8.

Group	N	Mean	Median	SD	Min	Max	% Remaining
AL Control							
0 Weeks	10	204.73	204.35	4.69	198.10	212.50	
8 Weeks	10	203.29	202.40	6.66	192.00	217.10	99.3%
AL Experimental							
0 Weeks	20	204.79	201.35	14.57	170.40	228.00	
2 Weeks*	20	122.68	118.15	26.05	79.50	169.00	59.9%
4 Weeks*	20	120.30	120.05	28.98	60.70	175.90	58.7%
6 Weeks*	20	114.79	116.75	26.16	53.90	163.10	56.1%
8 Weeks*	20	104.27	102.15	25.36	51.60	144.00	50.9%

Table 4. Pairwise comparisons of active ligature (AL) at Week 0, 2, 4, 6, 8.

Group	Time	Group	Time	Diff.	Lower 95% CI	Upper 95% CI	P-Value
AL Experimental	2 Weeks	vs AL Experimental	0 Weeks	-82.11	-99.53	-64.69	*0.000**
AL Experimental	4 Weeks	vs AL Experimental	0 Weeks	-84.49	-101.91	-67.07	*0.000**
AL Experimental	6 Weeks	vs AL Experimental	0 Weeks	-90.01	-107.43	-72.58	*0.000**
AL Experimental	8 Weeks	vs AL Experimental	0 Weeks	-100.53	-117.95	-83.10	*0.000**
AL Experimental	4 Weeks	vs AL Experimental	2 Weeks	-2.38	-19.80	15.04	1.000
AL Experimental	6 Weeks	vs AL Experimental	4 Weeks	-5.52	-22.94	11.91	1.000
AL Experimental	8 Weeks	vs AL Experimental	6 Weeks	-10.52	-27.94	6.90	1.000
AL Experimental	6 Weeks	vs AL Experimental	2 Weeks	-7.90	-25.32	9.53	1.000
AL Experimental	8 Weeks	vs AL Experimental	2 Weeks	-18.42	-35.84	-0.99	*0.022**
AL Experimental	8 Weeks	vs AL Experimental	4 Weeks	-16.04	-33.46	1.39	0.148

3.2.2 Force Decay of Elastometric Chain

Elastomeric chains showed a statistically significant force decay starting at week 2 (74.6% remaining) (Tables 5 and 6). This force decay continued throughout week 4 (71.9% remaining), week 6 (69.4% remaining), and week 8 (66.8% remaining). Similar to the active ligatures, elastomeric chains displayed the most significant force decay between week 0 and week 2. Additionally, the force decay was not significant between weeks 2, 4, 6 and 8, indicating a plateau in force decay.

Table 5. Force delivery of elastomeric chain (EC) at Week 0, 2, 4, 6, 8.

Group	N	Mean	Median	SD	Min	Max	% Remaining
EC Control							
0 Weeks	10	202.77	202.50	3.81	195.70	208.10	
8 Weeks	10	199.78	200.15	8.41	180.40	212.40	98.5%
EC Experimental							
0 Weeks	20	202.69	204.05	7.09	186.60	212.80	
2 Weeks*	20	151.24	150.25	8.14	138.30	168.70	74.6%
4 Weeks*	20	145.72	143.70	8.69	132.40	164.00	71.9%
6 Weeks*	20	140.65	138.10	8.53	126.70	155.60	69.4%
8 Weeks*	20	135.40	132.05	9.75	121.80	154.60	66.8%

Table 6. Pairwise comparisons of elastomeric chain (EC) at Week 0, 2, 4, 6, 8.

Group	Time	Group	Time	Diff.	Lower 95% CI	Upper 95% CI	P-Value
EC Experimental	2 Weeks	vs EC Experimental	0 Weeks	-51.45	-68.87	-34.03	*0.000**
EC Experimental	4 Weeks	vs EC Experimental	0 Weeks	-56.98	-74.40	-39.55	*0.000**
EC Experimental	6 Weeks	vs EC Experimental	0 Weeks	-62.05	-79.47	-44.62	*0.000**
EC Experimental	8 Weeks	vs EC Experimental	0 Weeks	-67.30	-84.72	-49.87	*0.000**
EC Experimental	4 Weeks	vs EC Experimental	2 Weeks	-5.52	-22.95	11.90	1.000
EC Experimental	6 Weeks	vs EC Experimental	4 Weeks	-5.07	-22.49	12.35	1.000
EC Experimental	8 Weeks	vs EC Experimental	6 Weeks	-5.25	-22.67	12.17	1.000
EC Experimental	6 Weeks	vs EC Experimental	2 Weeks	-10.60	-28.02	6.83	1.000
EC Experimental	8 Weeks	vs EC Experimental	2 Weeks	-15.85	-33.27	1.58	0.171
EC Experimental	8 Weeks	vs EC Experimental	4 Weeks	-10.32	-27.74	7.10	1.000

3.2.3. Force Decay of Nickel Titanium Coils

NiTi coils, unlike active ligatures and elastomeric chains, did not show statistically significant force decay throughout the 8 week time period (Tables 7 and 8). These coils maintained 93.5% of the initial force after 8 weeks.

Table 7. Force delivery of NiTi coils (NC) at Week 0, 2, 4, 6, and 8.

Group	N	Mean	Median	SD	Min	Max	% Remaining
NC Control							
0 Weeks	10	202.03	203.35	6.46	193.60	209.60	
8 Weeks	10	200.90	201.90	13.15	184.00	219.70	99.4%
NC Experimental							
0 Weeks	20	202.47	201.30	4.84	194.20	213.60	
2 Weeks	20	193.60	193.20	9.52	168.80	211.10	95.6%
4 Weeks	20	189.56	186.95	8.98	174.80	205.60	93.6%
6 Weeks	20	193.12	192.80	7.93	176.20	208.00	95.4%
8 Weeks	20	189.38	189.10	8.56	170.30	201.40	93.5%

Table 8. Pairwise comparisons of NiTi coils (NC) at Week 0, 2, 4, 6, 8.

Group	Time	Group	Time	Diff.	Lower 95% CI	Upper 95% CI	P-Value
NC Experimental	2 Weeks	vs NC Experimental	0 Weeks	-8.88	-26.32	8.57	1.000
NC Experimental	4 Weeks	vs NC Experimental	0 Weeks	-12.92	-30.57	4.73	1.000
NC Experimental	6 Weeks	vs NC Experimental	0 Weeks	-9.35	-27.01	8.30	1.000
NC Experimental	8 Weeks	vs NC Experimental	0 Weeks	-13.10	-30.75	4.55	1.000
NC Experimental	4 Weeks	vs NC Experimental	2 Weeks	-4.04	-21.26	13.18	1.000
NC Experimental	6 Weeks	vs NC Experimental	4 Weeks	3.56	-13.86	20.99	1.000
NC Experimental	8 Weeks	vs NC Experimental	6 Weeks	-3.75	-21.17	13.68	1.000
NC Experimental	6 Weeks	vs NC Experimental	2 Weeks	-0.48	-17.69	16.74	1.000
NC Experimental	8 Weeks	vs NC Experimental	2 Weeks	-4.22	-21.44	13.00	1.000
NC Experimental	8 Weeks	vs NC Experimental	4 Weeks	-0.18	-17.60	17.24	1.000

3.3 Comparison of Force Decay between Three Retraction Methods

At Week 0, there was no statistically significant difference in force delivery between the three groups (Table 2). Starting at Week 2, significant differences in force decay were noted between all three groups (Table 9). These differences were also seen at Week 4, 6, and 8.

Table 9. Mean comparisons between experimental groups at Week 2, 4, 6, and 8.

Week 2			Diff	Lower 95% CI	Upper 95% CI	P-Value
EC Experimental	vs	AL Experimental	28.56	15.63	41.49	*0.000**
NC Experimental	vs	AL Experimental	70.92	58.14	83.70	*0.000**
NC Experimental	vs	EC Experimental	42.36	29.58	55.14	*0.000**
Week 4			Diff	Lower 95% CI	Upper 95% CI	P-Value
EC Experimental	vs	AL Experimental	25.42	11.20	39.63	*0.000**
NC Experimental	vs	AL Experimental	69.26	55.04	83.47	*0.000**
NC Experimental	vs	EC Experimental	43.84	29.63	58.05	*0.000**
Week 6			Diff	Lower 95% CI	Upper 95% CI	P-Value
EC Experimental	vs	Al Experimental	25.86	12.96	38.76	*0.000**
NC Experimental	vs	Al Experimental	78.34	65.44	91.23	*0.000**
NC Experimental	vs	EC Experimental	52.48	39.58	65.37	*0.000**
Week 8			Diff	Lower 95% CI	Upper 95% CI	P-Value
EC Experimental	vs	AL Experimental	31.13	17.14	45.12	*0.000**
NC Experimental	vs	AL Experimental	85.11	71.12	99.10	*0.000**
NC Experimental	vs	EC Experimental	53.98	39.99	67.97	*0.000**

3.4 Force Decay of Control Groups

At week 8, the three control groups maintained their initial force (Tables 3, 5 and 7). No significant differences were found (Table 10).

Table 10. Mean comparisons within control groups - Week 8 vs. Week 0 (Baseline)

Group	Time		Group	Time	Diff.	Lower 95% CI	Upper 95% CI	P-Value
NC Control	8 Weeks	vs	NC Control	0 Weeks	-1.13	-25.77	23.51	1.000
AL Control	8 Weeks	vs	AL Control	0 Weeks	-1.44	-26.08	21.39	1.000
EC Control	8 Weeks	vs	EC Control	0 Weeks	-2.99	-27.63	21.65	1.000

3.5 Plot of Mean Force by Time and Group

The force measurements by group and time period can be visualized in Figure 14. Overall, NiTi coils maintained a consistent force over time (Table 7). Both the elastomeric chains and active ligatures experienced a large amount of force decay after 2 weeks and continued to decrease (Tables 3 and 5); active ligatures experienced the greatest force decay among the three groups. All control groups maintained their force over time (Table 10).

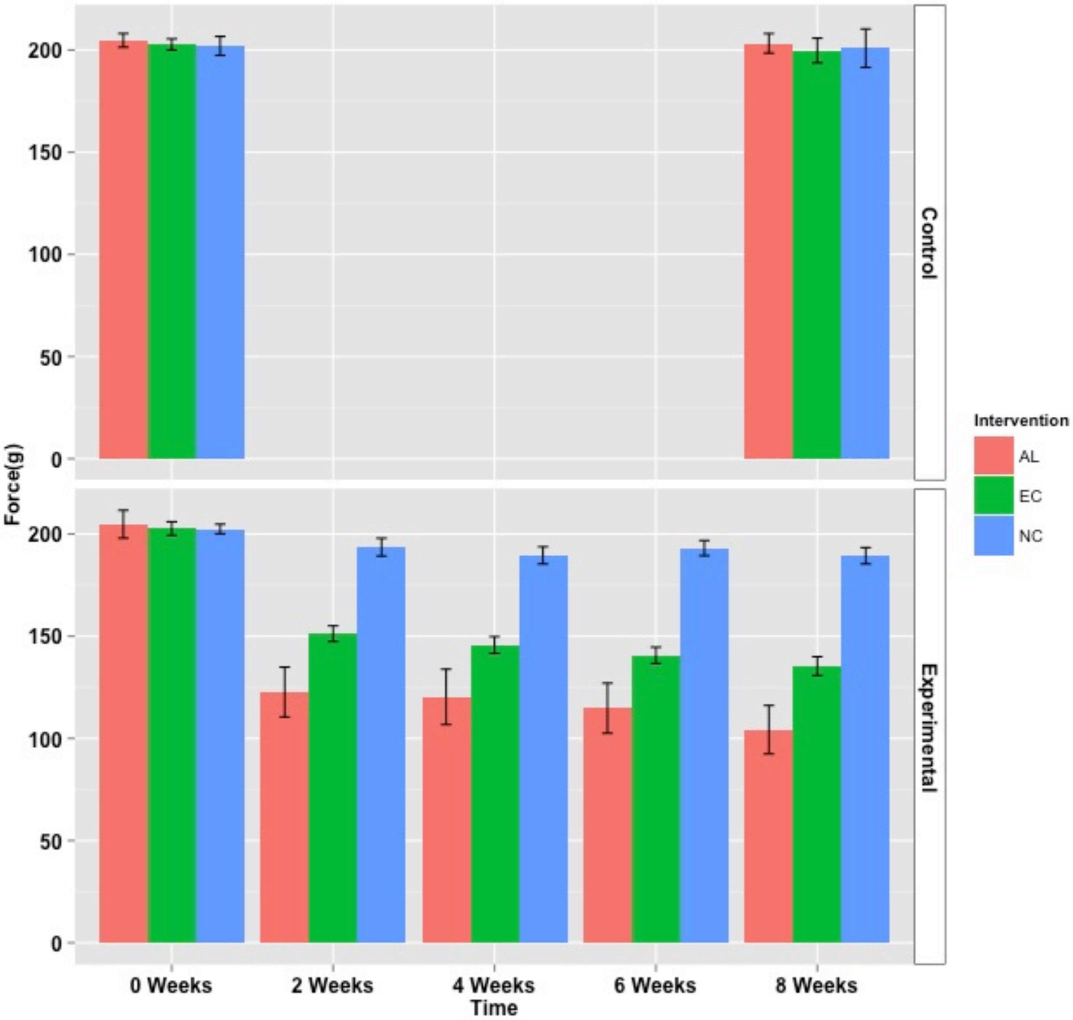

Figure 14. Plot of mean force by time and group

Chapter 4: Discussion

4.1. Limitations and Implications

The purpose of this study was to assess *in vitro* force decay under standardized environmental conditions that simulate the oral cavity. Multiple other *in vivo* factors have been shown to affect force decay, such as the presence of plaque, bacteria, high pH consumption, and mechanical loading.[31, 41, 51, 52] These conditions were not duplicated in the present study and the information gained from this *in vitro* study cannot be directly applied to an *in vivo* setting; the results may differ from what would be encountered in the oral cavity.[31]

Furthermore, coil springs and elastomerics produced by different companies may exhibit different behaviors; materials from different batches may differ as well.[31, 53-55] Small variations in alloy composition can alter mechanical properties and affect force delivery.[41] Thus, the analysis of data collected for this study is limited to the specific companies and materials selected. The materials chosen for the current study have tested superior to other companies and products.[7, 27, 28, 30, 31, 37, 42, 44, 56]

During initial activation, all of the samples were stretched to provide a force of 200 gm. This consistent force was easy to achieve in the elastomeric chain group as the same amount of links were used. For the active ligature group, there was a large variation in the force delivered by very minor twisting or untwisting of the stainless steel ligature. This led to initial force levels with an average of 200 gm but a much larger standard deviation when compared to the elastomeric chains and NiTi coils. . The activation of the NiTi coils was also very sensitive to small changes in the stainless steel ligature but the initial forces had a smaller range and standard deviation. All of this is important to consider as the materials are applied in the mouth in the same way. It has been noted that slight variability is always present in the application of the desired force.[33] Accordingly, the use of a force gauge is recommended to evaluate all forces being placed clinically.[57]

4.2. Evaluation of Retraction Methods within Groups

In order to evaluate all three methods of retraction, one must first assess the force properties of each sample group individually.

4.2.1 Elastomeric Chain

Throughout the years, several studies have revealed a large amount of force decay of elastomeric chains over time.[29, 45, 57, 58] Elastomeric chains have been found to lose a significant amount of force within the first 24 hours and maintain only 30 to 40% after 3 weeks.[6, 51] This is consistent with the results of other studies that observed the majority of decay to occur initially and plateau thereafter.[29, 58] More recent studies, however, have indicated that certain elastomeric chains may provide more favorable outcomes with regards to force decay over time.[27, 28, 31] Although the most significant decrease in force levels did occur after the first two weeks in the current study, the elastomeric chains proved to be more effective as they maintained more than 65% after 8 weeks.

The force decay of six units of Rocky Mountain Orthodontics (RMO) energy chain stretched to 30 mm at an average initial force of 241 gm has shown a similar pattern with a significant force decay after the first few hours.[37] At the time point of 2, 4, and 6 weeks, they found the amount of force remaining to be 72.6, 61.4 and 43.9%, respectively. At the six week measurement, the average force value remaining was 105.9 gm.[37] At the same time intervals, the current study found 74.6, 71.9 and 69.4% of force remaining. The force measurement of the current study at the six week time period was 140.6g.

Ten units of RMO energy chain were stretched to 100% extension at 330 gm and maintained 66% of the initial force after 4 weeks.[56] In comparison, ten units of RMO energy chain were stretched to twice the initial length (50% stretch) at 256.8 gm and maintained 59.2% (151.93 gm) after 3 weeks.[31] Furthermore, a study evaluating three units of RMO energy chain at a stretch of 20 mm with an initial force of 289.6 gm showed 63.1% of force remaining after 3 weeks.[27] Although the present study did not take measurements after 3 weeks, the elastomeric chains maintained 71.9% of its initial force after 4 weeks with 145.72 gm of force remaining.

These results indicate that 7-unit RMO energy chain stretched to 25 mm at 200 gm in the current study provides the best force delivery over time. It also supports the idea that a larger initial force of the sample may lead to a greater decay in force over time. Moreover, the memory type elastomeric chains similar to the energy chain used in the current study performed far superior with regards to rate of decay as compared to regular elastomeric chain.[53] These findings reveal the inherent variability in elastomeric chains and thus place emphasis on the importance of product selection and appropriate force application.[3, 31, 44]

Overall, the results of the current study demonstrate a statistically significant decrease in the force of the RMO energy chain over time. However, the findings are consistent with other studies and RMO energy chain appears to be superior in its capacity to retain a sufficient amount of force.

4.2.2 Nickel Titanium Coils

Over the years, numerous studies have evaluated the properties and performance of NiTi Coils. As discussed previously, NiTi coils are said to provide a light and constant force over time and thus have been widely promoted as the material of choice for sliding retraction. Product selection plays a extremely important role in clinical orthodontics as many manufactured coils do not express the desired force.[44]

The GAC Sentalloy 200 gm closed coil springs have delivered de-activation forces in the range of 201-243 grams.[44] Further evaluation of these coils at 9-10mm stretch and initial force levels between 187-211 gm have found 90% of the force remaining after 4 weeks.[42] In accordance with the previous finding, the GAC Sentalloy coils used in the current study delivered forces in the range of 189 to 193 gm when stretched to 12 mm (from the initial 9.6 mm). The minor force loss after 8 weeks (93.6% remaining) was not statistically significant.

On the contrary, GAC Sentalloy coils stretched to deliver a force of 150-160 gm were found have only 83.0% of force remaining after 4 weeks.[23] Coils stretched to deliver a force of 150-460 gm maintained only 52% of the initial force after 5 weeks.[11] The discrepancy between our results and these findings may be due to stretching outside of the desired range of 200g.

A recent comparison of *in vivo* and *in vitro* force decay of NiTi coils has found no significant differences between clinical and laboratory observations. After 8 weeks, the GAC Sentalloy NiTi coils were shown to maintain 82.6% of force *in vitro* and 81.1% *in vivo.*[7] The current study found that the GAC Sentalloy NiTi coils maintained 93.57% of the initial force after 8 weeks. It is very likely that coils in our study may behave similarly in the mouth and provide a consistent force as desired.

Overall, there was no statistically significant decrease in the force of the NiTi Coils over time in the current study. Our study reinforces and validates previous findings that the GAC-Sentalloy 200g coils are appropriate for delivery of light, continuous forces.[21, 39]

4.2.3 Active Ligatures

Few studies have evaluated the force characteristics of active ligatures as a method of retraction. Research has focused on the inherent properties of the elastomeric ligature itself. The current study was the first known *in vitro* comparison of active ligatures to the more commonly used NiTi coils and elastomeric chain.

An investigation of GAC elastic ligatures stored in an artificial saliva bath at 32°C revealed 34-58% of force remaining after 4 weeks.[30] Moisture and heat have been found to contribute to the decrease in dimensional stability and, therefore, the force levels of the elastomeric ligatures.[30] Furthermore, a study of stretched elastic ligatures found 42% of the initial force remaining after 6 weeks.[57] The active ligatures in the current study maintained 58.8% after 4 weeks and 55.9% after 6 weeks of stretch. Control group data has revealed that moisture and heat did not have an effect on force decay of the active ligatures in the current study.

The results of the present study reveal a statistically significant decrease in the amount of force provided by the active ligature over time. This large decay in force over time may be the reason why practitioners do not see the desired tooth movement.[57]

4.3 Evaluation of Retraction Methods between Groups

Finally, it is necessary compare the results between all three groups. At the two week measurement, the NiTi coils maintained 95.5%, while the elastomeric chain maintained 74.6% and the active ligature exhibited the greatest force decay with 59.9% of the force remaining. It is also interesting to note that the force values recorded for the active ligatures had a much larger range and standard deviation than the NiTi coils and elastomeric chain.

At the four week measurement, the NiTi coils maintained 93.4% of the initial force with the elastomeric chain at 71.9% and the active ligature at 58.7%. At this point in time, the difference between the two-week and four-week measurement was significant for both the elastomeric chain and active ligature groups as compared to the NiTi coils and to each other. A previous study showed that the elastomeric chains presented with a larger amount of force decay when compared to the NiTi coils, which presented with a gentle and progressive force decay after 4 weeks. One must take note, however, that the initial force of the elastomeric chains in that study, 347 to 404 gm, was much higher than that in the current study. The NiTi coil activation range of 196 to 223g was consistent with the current study.[6] The progressive decay in force produced by the NiTi coils as described in the previous study was not seen in the current study as the force remained constant.

After 6 weeks, the NiTi coils had 96.0% force remaining, the elastomeric chain had 69.4% and the active ligature had 56.0%. At the end of the 8 week period, there was no significant decrease in the force of the NiTi coils as 94.0% of the initial force was present. The elastomeric chain group had 66.8% remaining and the active ligature group 50.9% remaining. Similar to the previous time point, the elastomeric chain and active ligatures showed a statistically significant decrease in force as compared to the NiTi coils and each other.

4.4 Clinical Significance

If the results of this study were extrapolated to an intraoral environment, it would seem logical that NiTi coils produce the most consistent rate of space closure, followed by elastomeric chains and then active ligatures. However, the *in vivo* performance of NiTi coils, elastomeric chains, and elastomeric ligatures has differed from what would be anticipated from *in vitro* data.

NiTi coils and elastomeric chains have been shown to produce similar tooth movement clinically.[4, 11, 34] This may be the result of a greater amount of force maintained in the elastic chain than anticipated.[11] The question remains whether the higher cost of NiTi coils is justified over elastomeric chains as they both perform similarly in clinical application.[4, 34, 59]

On the contrary, NiTi coils provide a more rapid and reliable rate of space closure as compared to the active ligatures.[4, 40, 59] The average rate of canine retraction was greater in the NiTi coil group when compared to active ligatures.[3] NiTi coil springs have also been found to produce a more consistent rate of space closure *en masse* than an elastic module.[18]

The orthodontist must choose techniques and treatment modalities that are most beneficial to the patient and simultaneously minimize chair time/time missed from school or work.[4] NiTi coils are relatively more expensive but are easy to place and subsequently re-activate. Elastomeric chain is less expensive but takes longer to replace and may require more frequent activations. Active ligatures are also inexpensive but may require more total visits to achieve the desired tooth movement.[4] A systematic review to assess the efficacy of various methods of canine retraction concluded that all materials may be considered effective so long as they can overcome frictional forces.[5]

4.5 Effect of Environmental Conditions

In this *in vitro* study, the submersion in artificial saliva at 37°C did not have an effect on the force of the materials being studied. This is consistent with earlier findings that there was no difference in force decay between elastomeric chains stretched in air and intraorally.[52] However, various researchers have also shown that elastomeric chains exposed to an oral environment exhibited more force decay than those stored in air and water.[36, 45] Moreover, the oral environment such as pH, temperature and masticatory forces have been found to affect the properties of elastic materials, whereas NiTi coils were only affected by temperature.[29, 32, 51] Although we did control for pH and temperature, our study could not simulate any deformation that would occur due to chewing and biting.

4.6 Future Studies

With the current *in vitro* results, future studies may be performed to determine the force decay of these three methods *in vivo* under standardized force delivery or to compare the force decay amongst the methods stored in varying environmental conditions.

Chapter 5: Conclusions

In conclusion, there is a significant difference in the amount of force decay between three orthodontic sliding retraction methods over time under a standard initial force delivery of 200 gm over a 25 mm stretch. The NiTi coils have proven to maintain their force over time. Oppositely, the elastomeric chains and active ligatures both experienced statistically significant force decay over time. After comparing the data between the groups, it was noted that both elastomeric chain and active ligatures lost significantly more force over time as compared to the NiTi coils. The active ligature group also lost a larger and statistically significant amount of force as compared to the elastomeric chain. Ultimately, this would indicate a hierarchy of force loss with NiTi coils maintaining the largest amount of force, followed by the elastomeric chain and then the active ligature.

In terms of clinical application, it can be concluded that NiTi coils offer the light and constant force desired for efficient and biologically compatible tooth movement. This data also indicates to the orthodontists that longer appointment intervals are reasonable if NiTi coils are used. Active ligatures do not appear to be an effective means of force delivery. The question still remains as to the efficacy of elastomeric chains as they maintained a larger amount of force than expected and have proven to achieve comparable tooth movement to NiTi coils in clinical studies; they do need to be replaced more often and thus require shorter appointment intervals and more appointments overall.

Appendix A: Raw Force Data (gm) for Elastomeric Chains

EC 0 Weeks	EC 2 Weeks	EC 4 Weeks	EC 6 Weeks	EC 8 Weeks
208.8	168.7	160.5	155.4	154.6
205.7	157.4	156.4	149.5	144.8
202.7	144.2	139.3	132.6	128.4
201.0	145.8	139.4	133.1	129.7
207.0	150.4	147.6	141.3	137.0
206.1	153.0	145.8	137.2	132.1
208.0	154.8	151.5	146.4	141.7
201.9	138.8	132.4	126.7	121.8
206.1	144.9	135.3	134.0	126.2
202.2	147.8	141.7	136.3	128.3
192.6	153.9	147.8	147.0	139.5
204.0	159.4	154.0	150.5	148.7
191.6	160.7	153.9	147.8	146.2
204.1	148.4	142.5	137.5	126.7
208.8	165.7	164.0	155.6	152.4
191.2	146.1	143.1	135.9	131.8
201.3	151.4	144.3	144.4	133.2
211.3	138.3	134.6	127.6	122.6
186.6	145.0	139.4	135.4	130.2
212.8	150.1	140.8	138.7	132.0

EC Control 0 Weeks	EC Control 8 Weeks
195.7	180.4
201.9	201.2
201.7	203.8
205.2	212.4
205.7	205.1
206.4	197.6
208.1	199.1
202.6	198.4
202.4	204.8
198.0	195.0

Appendix B: Raw Force Data (gm) for Active Ligatures

AL 0 Weeks	AL 2 Weeks	AL 4 Weeks	AL 6 Weeks	AL 8 Weeks
199.5	85.4	83.0	82.9	74.9
217.0	112.7	108.9	109.4	101.2
221.0	164.1	175.9	163.1	144
185.1	102.0	60.7	53.9	51.6
228.0	148.7	136.1	136.4	128.4
218.5	150.1	154.2	90.8	91.8
196.6	158.0	149.6	139.1	143.8
209.6	105.4	106.7	126.9	95.4
170.4	134.5	129.6	119.5	114.1
200.7	134.3	131.5	130.2	110.3
199.7	169.0	150.0	141.0	135.6
198.1	79.5	71.9	71.0	62.5
193.6	96.5	123.9	121.2	97.8
200.1	94.7	97.2	108.0	84.0
202.0	138.4	149.2	145.5	128.1
189.7	120.0	111.5	114.2	91.3
222.6	116.3	116.2	107.1	91.3
223.1	110.7	103.7	102.0	103.1
206.7	120.0	131.6	119.1	121.1
213.8	113.3	114.6	114.4	115.0

AL Control 0 Weeks	AL Control 8 Weeks
203.6	205.8
209.4	198.3
206.4	202.1
201.5	199.2
212.5	217.1
205.1	202.7
201.0	202.0
209.5	192.0
198.1	208.4
200.2	205.3

Appendix C: Raw Force Data (gm) for Nickel Titanium Coils

NC 0 Weeks	NC 2 Weeks	NC 4 Weeks	NC 6 Weeks	NC 8 Weeks
197.7	193.1	189.1	188.6	185.5
204.7	183.4	185.0	186.0	179.0
204.3	196.1	190.7	198.4	196.3
203.1	186.8	186.8	190.3	190.9
200.2	168.8	180.0	180.0	170.3
203.7	196.4	198.6	193.4	177.7
201.3	187.1	181.2	190.2	186.6
201.0	202.8	189.0	200.1	196.2
200.3	211.1	204.8	202.4	201.2
210.5	206.6	205.6	208.0	201.4
206.9	193.2	185.6	192.2	191.5
195.7	206.6	201.5	202.5	201.2
194.2	189.5	184.5	193.5	188.2
200.7	185.9	183.1	187.3	186.6
207.9	191.4	184.2	176.2	177.4
198.4	186.6	174.8	187.5	188.2
202.5	188.6	180.8	191.3	189.8
213.6	200.6	202.8	194.1	188.4
200.3	195.0	195.9	198.5	194.1
200.8	195.1	187.1	201.9	197.0

NC Control 0 Weeks	NC Control 8 Weeks
201.2	209.4
198.2	195.4
194.4	186.2
205.5	204.8
194.3	184.0
193.6	184.3
207.2	199.0
209.6	215.0
208.6	219.7
207.7	211.2

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