THE FORCE DECAY BEHAVIOR OF ORTHODONTIC ELASTOMERIC CHAINS AS A FUNCTION OF TIME AND ELONGATION

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INTRODUCTION

C-chain modules are a popular means to ligate, consolidate, and retract teeth. While their ease of use and ability to create a force for tooth movement are impressive, they are not without problems.

In addition to the mechanical obstacles such as iatrogenic tipping and rotation of teeth, there are also dilemmas with the material: inconsistent forces, water absorbtion, discoloration, and bulky size. Manufacturers are driven by a competitive market to improve on these characteristics and are constantly developing "new and improved" c-chains.

The manufacturers claim their newest generation of chains, often referred to as "Generation II" or "Super Energy" (as opposed to the older "Power" chains), are much improved. GAC states that their GAC Chainettes "deliver evenly distributed, consistent force; absorb less moisture than plastic; have less bulk; and are non-traumatic to the patient" (1). The older elastomeric chains are known to be made of polyurethane, however the composition of the newest chains is guarded proprietary information. Clinicians have expressed their subjective opinions that these new modules do retain more elasticity after several weeks of use, and that the teeth seem to move faster. Research indicates that at least one new chain may provide more consistent force (2), however, tooth movement has not been shown to be enhanced (3).

The purpose of this study is to compare the force decay of an older chain (Unitek Alastik spool chain) and two newer generation chains (Rocky Mountain Energy Chain and GAC Chainette) at four different elongations in a static in vitro environment over a four week period. The results, quantified as percent force decay and grams of remaining force, should provide the clinician with a rational basis for choosing an appropriate chain, as well as a guideline for the degree of elongation of the chains necessary to achieve a desired force.

REVIEW OF THE LITERATURE

Two orthodontic elastic materials which have been studied with regard to force decay are the rubber elastics and the synthetic polyurethane (plastic) elastics. These materials each have their own properties of decay. Originally, the rubber elastics were formed into bands of various sizes and used for intra-arch and inter-arch tooth movement. The polyurethane plastics were formed into chains, ligature modules and straight KX units, and used for intra-arch tooth movement and ligation. The formulations of the newest "second generation" c-chains are still proprietary information, however advertisements for GAC Chainette (1) indicate that they are not plastic elastics. An introduction to the chemistry and physical properties of elastics is presented first to provide an understanding of the material itself and a theoretical basis upon which to evaluate the experimental results.

Chemistry

Rubber is an amorphous, elastic, solid polymer of isoprene $(C_5H_8)_n$, light cream to dark amber in color. It is prepared by coagulation and drying of the milky sap (latex) of the tropical rubber tree, Hevea brasiliensis, which is then modified for use. The polymer is a long thread like molecule and randomly coiled. When stretched, it becomes a linear chain, and coils back when released (4).

Polyurethanes are addition polymers made by reaction of an isocyanate and a polyol. They not only have the resiliency of rubber, but they also have the rigidity of plastics and have thus replaced rubber in numerous products. Polyurethane used for orthodontic modules are thermoplastic elastomers (TPE), a material which changes from the processible melt to the solid rubber-like product rapidly upon cooling. These elastomers can have properties similar to vulcanized rubber but production is not as slow and energy intensive and they can be produced on thermoplastic equipment (5). The modules are either injection molded or cut from an extruded ribbon. Scrap is not recycled during module production for improved quality control (6).

The TPE are formed of alternating block copolymers. Each segment of the hard, highly polar, crystallizing polyurethane is linked by an amorphous elastomeric block (polyester or polyether) which is rubber-like at normal room temperature. The crystalline polyurethane melts with heat (typically 400·F for injection molding) and the material becomes fluid. When cooled, the polyurethane crystallizes, and the soft segments are linked forming a solid state structure. A polyether elastomer block is preferable to polyester elastomer block if long-term exposure to water or dilute acids of alkali solutions is anticipated because these conditions promote hydrolysis of the ester links. TPE's are polar materials and thus can only be blended with other polar polymers (5).

Properties of Plastics

Plastics are viscoelastic, meaning that they display properties intermediate between crystalline metals and viscous fluids. As such, their properties, such as load bearing under tension, compression, and bending, are evaluated somewhat differently than those of metals. The stress-strain curve of a metal (typically containing a proportional limit, elastic limit, yield point, and ultimate strength) is insensitive to temperature changes (except extreme) and to rates of loading. Plastics, on the other hand, vary their stress-strain patterns according to these variables. Plastics flow at much lower stresses than metals, and under a static load, the deformation and rupture of plastics is affected by the time under load. For this reason, stress-strain tests are not used as often to simulate the use of plastics, as they are with metals. Plastics are evaluated by creep tests (time studies), with variables such as temperature, strain rate, and stress level. The creep of plastics under a static load, where they deform rapidly at first according to a stress-strain modulus, and then more slowly over time, also occurs in metals, but usually only in soft metals or structural metals at high temperatures and pressures (5).

The viscous behavior of plastics leads to chain slippage which is slow and irreversible, while their elastic behavior consists of stretching and uncoiling which is quick and reversible (2). If the rate of loading is varied, the stress relaxation can be affected because viscoelastic mechanisms respond to short time loads. The more viscoelastic the plastic is, the more sensitive it will be to the rate of strain. Therefore, for ideal testing conditions, the rate should be standardized, and the initial force recorded at a specific time following loading, such as 30 seconds (5).

Two other factors which affect stress relaxation are water absorbtion and fatigue. Water absorbtion typically results in plasticization which can cause dimensional expansion, relaxation of molded in stresses (leading to warpage), softening, and reduced strength, stiffness and creep resistance (5). (GAC advertisements (1) claim that their chainette absorbs less moisture than plastic chain). Fatigue results from exposure to cyclic load and is complex, requiring test conditions to closely match those conditions found in use (5).

Experimental Conditions

Chain decay testing is performed by stretching a chain a given length, measuring its initial force, storage of the chain at this length for some time, and then remeasuring its force. The conditions of storage will effect the force decay of the chain. Conditions which simulate the in vivo environment, yet simpler in use and with minimal chance of introducing error and variation, are sought.

Early work was done by Andreason and Bishara (7,8) in a pilot study of force decay in plastic alastiks and rubber elastics using air, water and saliva as storage testing media. They found no significant difference between 37 degree water storage and saliva storage for plastic alastiks, nor room temperature water and saliva storage for rubber elastics. Other temperature phenomenon such as thermal cycling of plastic modules from 15 to 45 degrees Celsius twice a day (simulating ice water and coffee) was found to result in lesser force decay by DeGenova, et al (2). However, Brooks and Hershey (9) reported that heat, simulating a "hot beverage" increased force decay in plastic modules. Thus, the effect of temperature cycling is still not known.

A comparison of in vitro (air or water) versus in vivo conditions, by Ash and Nikolai (10) (using Unitek's K-1 and CK gray chain) supported the findings of Andreason and Bishara (7,8). They found that force degradation was significantly more rapid in water than in air after just one hour. They also found that after one week, force degradation was greater in vivo than in 37 degree Celsius water, but that this difference was only 1.5 ounces and thus of questionable clinical significance. In another investigation, by Howard and Nikolai (11), room temperature air was compared to in vivo conditions while studying latex and polyurethane threads. Initially, the air samples decayed faster, but then a "cross-over phenomenon" occurred whereby the air sample decayed much slower than the in vivo samples, and the in vivo samples ultimately showed the greatest force decay. They noted this cross-over was also seen in the Ash and Nikolai study.

In a more recent investigation of in vivo and in vitro test conditions, Kuster, et al (12) reported that air stored modules experienced significantly less force decay than in vivo modules (which were kept at a constant extension). Unfortunately, they did not compare with 37 degree water storage.

The final condition of experimentation is the rate of elongation. As was mentioned previously, differences in the rate of strain in a plastic can alter stress relaxation curves. Kovatch, et al (13) studied this in Unitek K2 alastiks and their results support this. A comparison of rates (0.2, 2.0 and 20 inches/minute) revealed that rapidly stretching the modules resulted in initial high forces followed by greater force decay and ultimately reaching a lower final force. The higher rate also resulted in breakage of the alastic at lower force values during strength testing. They also noted however, that these differences were "not necessarily of sufficient magnitude to seriously influence the clinical result." A difference in extension speed of a factor of 100 (0.2 versus 20 inches/minute), resulted in only 1/10 pound difference in force.

Methods of Measurement

Numerous types of gauges have been used to measure the force of the materials. Gauges may be either hand held or mounted for better control. Some have rulers attached to elongate the material to a specified length, whereupon the force is measured. Young and Sandrik (14) noted that these gauges can be inaccurate, and used the Instron Testing Machine, as had Kovatch (#13) and Varner and Buck (15,16) previously.

Most methods involve the removal of the elastic from its jig and placement onto the measuring apparatus, causing possible relaxation and stretch cycling of the material. An Instron Testing Machine can be fitted with a jig which can both store the modules and hold the modules for measurement. The module is stretched only slightly beyond its test length, measured, and returned (15,16), thus reducing any significant cycling.

Bishara and Andreason (8) have reported that drying of water-stored elastics results in higher force measurements. This, of course, could increase error if the modules were not measured under identical moist conditions. Of the studies reviewed, all removed the modules from their watery media to be measured.

<u>Tooth Movement</u>

Just how many grams of force is ideal to move a tooth has been estimated by numerous studies. Reitan (17) determined this optimal force to be 150 - 250 grams for a maxillary canine and 100 - 200 grams for a mandibular canine. Quinn and Yoshikawa (18), after critically reviewing numerous clinical studies by Smith and Storey, Andreason and Zwanzinger, Hixon, et al, Boester and Johnston, and Andreason and Johnson, found 100 - 200 grams ideal for cuspid retraction. The rate of tooth movement estimated by Hixon, et al (19), Paulson, et al (20) and Huffman and Way (21) averages approximately 1 mm per month, utilizing forces between 50 grams to 1500 grams. However, the range is considerable, with 0.4 to 1.7 mm per month reported by Paulson (20) using elastics changed daily. Hixon, et al (19,22) suggested that forces higher than 300 grams result in faster tooth movement and that an optimal force may not exist. Huffman and Way (21) also found that tooth movement, using sliding mechanics, along a larger arch wire (.020 SS) does not require any more force than sliding along a smaller arch wire (.016 SS). Clinically, forces utilized vary greatly, from the 50 grams exerted by elastics (20) to over 1000 grams. For example, a Bull loop of .0215 by .025 SS activated to a "thin dime," exerts greater than 1 kilogram of force (19).

Results of Previous Experiments

Investigators have studied elastomeric force decay under three main conditions: static, dynamic, and prestretching. Static experiments involve stretching the modules a fixed distance and holding them there for the remainder of the experiment. This condition simulates teeth which are not appreciably moving, such as found during tooth movement initiation. Dynamic experiments entail shortening the distance, usually weekly, to simulate tooth movement. Lastly, prestretching, a common clinical practice, involves stretching the elastomer prior to placement on the jig, in an attempt to reduce the initial force and force decay.

Static

Andreason and Bishara (7) evaluated alastik chains (in 37 degree water) and rubber elastics (in room temperature water) at various elongations over a three week period. Force was measured with a gauge, removing the modules from their jigs to measure them. They found the greatest decay in the first hour: 56% for alastiks and 27% for elastics. Force decay by 24 hours was 74% for alastiks and 42% for elastics. Following this initial rapid drop, decay was only 8% for alastiks and 5% for elastics over the next 3 weeks. They also compared standard and heavy chain alastik. The heavy chain exhibited higher initial forces but decayed faster, yielding lower final forces than the standard chain. They recommended applying an initial force 4 times greater than the desired final force when using chain alastik to compensate for the 75% force decay.

A second study by Bishara and Andreason (8) evaluated K1, K2, and K3 alastiks, and various rubber elastics under the same conditions of their previous experiment. Decay at 1 hour was 10% for elastics and 45% for K units; at 1 day was 17% for elastics and 55% for K units; and at 3 weeks was 25% for elastics and 67% for K units. The type of elastic made quite a difference in force decay. For example, a 3/16" 6 oz. Ormco stretched to 22 mm yielded a 19% loss while a 4/16" Rocky Mountain stretched to 22 mm yielded a 53% loss with only one-half the initial and one-third the final force of the 3/16" 6 oz. Ormco elastic.

Wong (4) evaluated numerous properties of natural latex and synthetic polymers. In comparing tear strength, using a mounted gauge, the latex showed greater resiliency and strength in air, but also greater loss of strength after immersion in water. In a comparison of force decay over 24 hours, Ormco Power chain lost 50% and Alastik chain lost 73%, when stored in 37 degree water. Since the force after 24 hours was the same (171 grams), while the initial force for the Alastik was much higher (641 grams versus 342 grams), he suggested the Alastik may cause more patient discomfort.

Varner and Buck (15,16) evaluated Kx-2 alastiks stretched to lengths simulating the range of distance found between a distal molar and an arch wire hook (28 - 38.6 mm, mean 34.5 mm). Kx units were stored in 37 degree water and measured with an Instron Testing Machine without removing the units from their jigs. Measurements were made from 2 hours to 4 weeks. Analysis of covariance of regressions lines of the various elongations revealed that the slopes were not statistically different, and hence, decay rate was similar regardless of elongation. Force decay from 2 hours to 4 weeks was 26% for pooled data, and a two-way analysis of variance indicated that the force plateaued at about 2 weeks.

In a study conducted by Doyle (23), Unitek alastik chain was tested in vitro, in 37 degree water, on a jig utilizing brackets which simulated the in vivo condition of stretching the chain over brackets rather than hooks only. The chains decayed 36% by 2 hours, 39% by 24 hours, and 44% by 4 weeks.

In a 1985 study by Killiany and Duplessis (24) a new "second generation" chain, Rocky Mountain Energy Chain, was compared to American Orthodontics Plastic Chain (both closed link). The chains were stretched to 2 times their original length, stored in a 37 degree C saliva pool, and measured with an Instron Machine, for 8 weeks. Rocky Mountain chain with an initial force of 330 grams, lost 34% by 4 weeks, and 45% by 8 weeks, with a final force of 183 grams. By contrast, American Orthodontics chain, with an initial force of 375 grams, lost 67% by 4 weeks, and 73% by 8 weeks, with a final force of 102 grams. He concluded that the new generation chain was an improvement.

In a 1986 study (previously mentioned) by Kuster, et al (12), Unitek Alastik chain and Ormco Power Chain II were tested in vitro (in air) and in vivo at constant extension (static). By 4 weeks, air stored modules of Unitek lost 30%, while Ormco lost 26%. In vivo modules of Unitek lost an additional 27% for a total of 57% decay, while Ormco lost an additional 22% for a total of 48% decay.

Dynamic

A 1975 study by Hershey and Reynolds (25) compared Unitek chain, Ormco Power Chain and TP Elast-O Chain in an in vitro simulated tooth movement model. Modules were stored in 37 degree

C water for 6 weeks. After 4 weeks, the static modules lost 60%, while the 0.25mm/week closure rate modules lost 68% and the 0.5mm/week closure rate modules lost 75% of their initial force. After 6 weeks, the 0, 0.25, and 0.5 mm/week modules had lost 58%, 72% and 82% respectively. Analysis of the effect of initial force on force decay (in modules subjected to the 0.5mm/week space closure) revealed modules experienced greater force decay in the first 24 hours when stretched to higher force levels, but the subsequent force loss was greater in the modules with the lower initial force levels. The Unitek alastiks exhibited less force decay in the first 24 hours, but by 4 weeks, all chains were similar.

Porter (26), in 1980, studied the effect of space closure of approximately 1/4 mm per week on Unitek Alastik inject molded and punched C1 chains. Chains were stretched over brackets on jigs, simulating teeth in a first bicuspid extraction arch, and stored in 37 degree C water. Measurements were made with a mounted gauge. The mean force of the injected molded chains was 1057 grams at 0 hour and 214 grams at 4 weeks. The mean force of the punched chains was 986 grams at 0 hour and 264 grams at 4 weeks. Analysis of variance revealed that the molded chains had significantly more force until 3 weeks, and the punched chains had significantly more force at 4 weeks.

DeGenova, et al (2) studied three products, Rocky Mountain Energy Chain, Ormco Power Chain II and TP Elast-O Chain, in 37 degree C synthetic saliva, and measured force with a digital electronic force gauge. Reported standard deviations were fairly low, and thus significant differences between products and conditions tested were discernable even when results varied by only a few percent. As mentioned previously, DeGenova showed temperature cycling reduced force decay (by approximately 4% at 3 weeks), and all remaining tests were carried out under temperature cycling 2 times per day for 30 minutes. At constant lengths, Rocky Mountain chain exhibited statistically less percent force decay (39%) than TP chain (45%) and Ormco chain (58%), after 3 weeks. At decreasing lengths in a dynamic study (0.5 mm/week) Rocky Mountain chain lost an additional 12% for a total of 51% decay, TP chain lost an additional 13% for a total of 58% decay, and Ormco chain lost an additional 9% for a total of 67% decay.

Rock, et al (27) tested 8 products in vivo over 4 weeks in first bicuspid extraction cases. For the final force measurement, the modules were removed from the mouth, stored in tap water, and tested on an Instron Machine within 24 hours. Each product was tested only 6 times and at various extensions, so meaningful correlations were not found between brands, amount of tooth movement, or force reduction. Overall, the chains decayed 40% over 4 weeks (range 19% - 59%).

In a more extensive study by Sonis, et al (3), the efficacy of Unitek elastic thread, Unitek elastic chain and Rocky Mountain chain to close space in 25 patients was measured. Paired quadrants received elastic thread on one side, and either Unitek or Rocky Mountain chain on the other side. No attempt was made to measure the force of the elastic chains, only tooth movement was measured. Mean rate of tooth movement for the Unitek elastic thread (pooled) was 1.2mm +/- 0.5mm; for the Unitek chain 1.0mm +/- 0.4mm; and for the Rocky Mountain chain 1.5mm +/- 0.6mm. A test of variance revealed no significant differences.

Prestretching

A 1979 study by Young and Sandrick (14) evaluated the effects of prestretching Unitek Alastic CK and Unitek Alastic C2 chain on force decay over 24 hours in 37 degree C water. The four link chains were prestretched quickly by hand to 14 or 23 mm for the CK modules and 18, 36 or 48 mm for the C2 modules. They were then loaded to 90 grams on an Instron Machine. The CK modules exhibited statistically significant decreased force decay, with the control modules decaying 56%, and the 23 mm and 14 mm prestretched modules decaying 45% and 49%, respectively. However, the C2 modules did not exhibit reduced force decay with prestretching, and the authors could not provide an explanation for this different response.

Another 1979 study of prestretching, by Brantley, et al (28), examined prestretching Unitek Alastik C Spool chain and Ormco Power Chain II to twice their original lengths, and storage at this length for either 1 day or 3 weeks, in either room temperature air or 37 degree C water. The modules were then placed onto jigs either immediately, after 1 day, or after 1 week, and then stored for 3 weeks. The modules which were prestretched for 3 weeks in water and immediately placed onto the jigs showed the least force decay (from 441 grams prior to prestretch, to 130 grams after prestretch, to 122 grams after 3 weeks - a loss of only 8 grams). Air stored prestretched modules showed less dramatic decreases in force decay. The same was true for those prestretched modules allowed to sit for 24 hours or a week prior to placement on the jig. All prestretching, regardless of how performed, yielded some amount of reduced force decay, although the authors felt that prestretching in air for up to three weeks was not effective in obtaining modules with near constant forces. Both brands behaved similarly to the effects of prestretching.

MATERIALS AND METHODS

Force decay of three brands of chain elastics were evaluated at four different elongations. Modules were stored and measured in 37 degree distilled water, making force measurements with an Instron Testing Instrument. The three chains selected (all gray, closed chains), Rocky Mountain Energy Chain, GAC Chainette (both "second generation" chains), and Unitek Alastik Spool Chain (a polyurethane chain) were purchased directly from the companies and stored in the dark in zippered sealed bags until use. 120 elastic modules were tested: 3 (brands) X 4 (elongations) X 10 (n). Force was measured at 30 seconds, 24 hours, 1 week, 2 weeks, 3 weeks, and 4 weeks.

Phase I. In an initial phase, force evaluations were made to determine four elongations which would encompass both low and high forces, without breakage of the chains. These measurements were made with a force gauge under dry conditions, and 23%, 93%, 205%, and 346% elongations were selected for study.

Phase II. Jigs were fabricated from aluminum sheeting formed into rectangular boxes. Each box was 58 mm in height (the test length). The chain elastics were cut randomly from their spools into the four different lengths (13, 19, 30, and 47 mm) and placed into the aluminum jig using short pieces of .062 SS wire in a systematic randomized order. Eight elastic modules were set in each of 15 jigs (See Figures 1 and 2). The jigs were mounted inside sealed water-tight plastic electrical gang boxes and fastened down with screws and plates. The boxes were placed in a constant 37 degree Celsius water bath and temperature equilibrated. A box containing the jig and 37 degree water, was then mounted on the Instron Testing Machine on a sliding platform (See Figures 3a and 3b). Each chain was stretched at approximately the same rate, by hand, utilizing a string tied to an extra chain loop at the end of the chain with which to lift and stretch the elastic. Another piece of .062 SS wire (with a pointed end) was placed through the chain loop (just below the extra loop) to hold the chain at its new length. Thirty seconds following activation, the force on the chain was measured using a fork on the Instron Testing Instrument to lift the .062 SS wire holding the chain (See Figures 1 and 4). The force at the moment of lift off was recorded on graph paper and the fork immediately lowered, returning the chain to its original test length. The sliding platform was then moved to align the next chain for testing. This procedure was repeated for each of the 120 modules.

Subsequent measurements were performed the same way. Rust unfortunately developed on the screws and plates which were used to hold the jigs in their boxes. The consequences of this are unknown.

RESULTS

Each brand of chain elastic was plotted separately on graphs portraying force versus time (See Figure 5) for each elongation tested. As can be seen, Rocky Mountain Energy Chain (RMO) and GAC Chainette (GAC) achieved higher initial forces than Unitek Alastik (UNI). In addition, most force was lost during the first 24 hours, and the more an elastic was stretched, higher forces, as well as higher force decay, resulted.

The percent force decay over 4 weeks:

(initial force - final force) / initial force

was then plotted against the initial force (See Figure 6). Both standard deviations and standard error of the means are portrayed on the graph. Each data point represents a sample of 10 modules at a particular elongation, and lines are drawn connecting the data points only to indicate each brand. UNI had the greatest force decay at all elongations, ranging from 46% to 55%. RMO and GAC had similar force decay values at higher elongations (approximately 30%), however at 23% elongation RMO had only 17% force decay while GAC had 27% force decay.

Two graphs of final force versus initial force were plotted, one as mean data points (See Figure 7), and the other as regression lines of log force, with the standard error of the estimates at the ends of each line (See Figure 8). Due to the greater variance of the data at higher forces, the log transformation was performed to satisfy the statistical condition of homoscedasticity (an array with equal variance) for regression lines (29). The coefficient of correlation of each line is 0.99 or greater. Linear equations (not log) for each regression line are as follows:

1. To calculate final force from initial force:

RMO	$Y = 50.5 + 0.62X$
GAC	$Y = 12.0 + 0.69X$
UNI	$Y = -17.8 + 0.58X$

Y = Final force (grams) X = Initial force (grams)

2. To calculate initial force from final force:

RMO	$Y = -72.2 + 1.59X$
GAC	$Y = -13.1 + 1.44X$
UNI	$Y = 37.3 + 1.69X$

Y = Initial force (grams) X = Final force (grams)

From these equations, a final force may be calculated from an initial force (or vice versa) for each brand. For example, an initial force of 400 grams would yield a final force of approximately 299 grams for RMO, 288 grams for GAC, and 214 grams for UNI (See Figure 7). Two sets of equations are necessary because a regression line of Y on X is not the same as a regression line of X on Y. The dependent variable (Y) and independent variable (X) have been switched. Therefore, the two sets of equations will yield different results and should be used accordingly (29).

A prediction table of force resulting from various elongations of each brand was calculated from regression lines of percent elongation versus final or initial force (See Table 1). The elongation is presented both as a percentage and as a factor of "times original length" for ease of understanding.

Finally, percent elongation versus percent force decay (over 4 weeks) was analyzed. Again, lines were drawn between data points to indicate each brand (See Figure 9). A two-way analysis of variance (alpha = .05) was performed for elongation and brand of material. The overall means (averaging all four elongations) of each brand of chain elastics were found to be statistically different (See Table 2). The calculated contrast number (2.88) represents the minimum difference (for alpha = .05) between any two means which are statistically different. If the means are any closer than 2.88, then the null hypothesis would not be broken. Since each mean differs by more than 2.88, each mean is statistically different from the others.

The analysis of variance of the individual means is portrayed in Table 3. The contrast number is 4.05 (for alpha = .05), and boxes encircle those means which differ by less than 4.05, and are thus not statistically different. While many statistical differences may be gleaned from this table, those of the most importance are as follows:

1. UNI has the greatest percent force decay of any brand at all elongations tested (from 46% to 55% force decay).
2. RMO has the least percent force decay of any brand at 23% elongation (only 17% force decay).
3. At 205% and 346% elongation, RMO is similar to GAC.

4. Percent force decay of GAC (from 25% to 30 force decay) is nearly independent of percent elongation (nearly 0 slope).
5. Percent force decay of RMO is the least at 23% elongation and the most at 346% elongation (positive slope).
6. Percent force decay of UNI is the greatest at lower elongations and the least at higher elongations (negative slope).

For error analysis, eleven chains from two boxes were remeasured following measurement of the entire set, during the third week of testing. The standard error of measure, calculated from:

$$\sqrt{\frac{\sum d^2}{2N}}$$

was 2.6 grams or 1.1% of the mean final force of all the modules.

Tables 4, 5, and 6 contain the force raw data (in grams) which was converted from pounds recorded by the Instron Testing Machine. Table 7 lists the descriptive statistics of the force raw data. Variance is greater at the 0 hour time point. Table 8 contains the percent force decay and related descriptive statistics.

DISCUSSION

As also seen in previous studies, most of the force is lost in the first 24 hours. From this standpoint, the higher initial force is irrelevant, except for possibly two factors which may be caused by this high force: (1) initial pain experienced by the patient, and (2) ischemia and undermining resorption. Studies by Sonis, et al (3) and Boester and Johnston (30) have found no link between pain and force. However, this lack of correlation may be due to the large variation both within and among patients, as reported by Boester and Johnston (30). Thus, despite the lack of evidence, many clinicians may still intuitively feel higher forces will cause more pain.

With regard to higher force causing ischemia and undermining resorption, Sonis (3) found that the heavy and light forces both resulted in similar rates of tooth movement. He speculates however, that the process may occur through different physiologic mechanisms with the light forces resulting in a slower starting and a gradual tooth movement, while the heavy forces create a more rapid initial tooth movement followed by a longer lag phase due to undermining resorption. Other researchers (26,31) have indicated that excessive force could slow down tooth movement due to necrosis. Thus, re-initiating the lag phase with high forces when the chains are replaced could be detrimental. A chain without an excessive initial force would be advantageous in this respect, by maintaining a more continuous force.

Whether the average force exerted by a chain is light or heavy is again the personal preference of the clinician. The existence of an ideal force for tooth movement has still to be absolutely proven or disproved. If heavier forces are preferred, careful measures to control rotation, tipping, and possibly anchorage, will be required by the use of wire ligature ties, heavy arch wires and extra anchorage. Obviously, a clinician who normally uses light force and unknowingly introduces a heavy force elastic into his mechanical scheme, may loose control of several aspects of treatment. For all of the above reasons, knowing the force of the elastics and utilizing them to a personal best advantage, is desireable.

The results of this study revealed significant differences between the three brands. The Unitek Alastiks have significantly lower final force values than the other two brands. It also exhibits a greater force decay. This lighter force is probably desired by some clinicians, while the greater force decay is not. The magnitude of the differences between the brands is clinically relevant. For an approximate final force of 230 grams, Unitek chain would require stretching to 4 times its original length, while Rocky Mountain chain would only be stretched to 2 times its original length (see Table 1). Using 34.5 mm as the average distance from a posterior molar to the arch wire hook calculated by Varner (15,16), approximately 4 links of Unitek, versus 7 links of Rocky Mountain, would be used to achieve this force. The link lengths are not a 2 to 1 ratio, as would be expected, due to rounding to the nearest link number, and because length was initially measured from the inside of the donuts of the end links, rather than the beginning of one link and the end of the other link).

Not only is it difficult to anticipate the final force of an unknown product without experimental determination of force decay, it may also be very difficult to evaluate the initial force by "feel." The modules in this study were stretched by hand. At any given elongation, the Unitek chains were subjectively felt by the operator to be the stiffest, giving the impression of higher force. In actual fact, the Unitek chain yielded the least amount of initial force and thus did not correlate with stiffness. However, in a previous study by Wong (4) where the stiffness was quantitatively measured by gauge, the higher stiffness of the Unitek Alastik chain did correlate to a higher initial force, when compared to the more resilient and elastic Ormco Power Chain. Its importance lies in the error which may occur if more than one type of chain is used by an operator, who may "feel" that the proper force is exerted, when in fact it is too high or too low.

The results of this study, and others, are reported as percent force decay, not just force decay. This is useful because it simplifies comparison of brands and results of different studies, and yields a nearly flat slope line because the force decay is related to the initial force. Higher initial forces exhibit higher force decay, but never yielded a final force lower than the final forces yielded by lower initial forces (ie: the lines are parallel without cross-overs (see figure 1)). By relating force decay to the initial force, as percent force decay, this common effect is hidden, allowing the relationship of percent force decay to elongation (or force) to be nearly a flat slope line, and thus highlighting some other interesting phenomenon, as will be seen.

While the analysis of variance revealed little relationship between percent force decay and initial force for GAC chain (a nearly flat line), this was not the case for the other two brands (See Table 3 and Figure 6). It is thus necessary to test elastics over a range of clinically useful force levels because the percent force decay can vary with initial force, to a statistically significant amount. The Rocky Mountain chain decayed more with greater elongation (31% compared to 17%) while the Unitek chain decayed less with greater elongation (46% compared to 55%). Therefore, final force cannot be predicted by calculation from just a single mean percent force decay, whether averaged from several test elongations or from just one arbitrarily chosen elongation. Calculations from regression lines as presented here are the most useful.

The techniques used for this study yielded relatively low variances and thus, data useful for making comparisons between chains. Several aspects which probably contributed to this are the minimal cycling of the chains, the lack of air drying during force measurement, and the use of the Instron Testing Machine to accurately measure the force. The greater variance at the 0 hour time point is probably the result of inexact time measurement (which should have been a uniform 30 seconds following activation), and the use of hand stretching, rather than machine stretching of the elastics, resulting in unequal rates. In addition, and probably most importantly, errors in lifting the cross-bars (slightly sideways) occurred, making interpretation of the Instron force graphs more difficult. At later time points, any such errors were eliminated by repeating the lift. However, at 0 hour, the force decay is so rapid that second measurements are not valid (too low). All of these problems could probably be eliminated by using a different technique for measuring at 0 hours. The elastic could be raised by a hook and held at the proper height for 30 seconds and then the crossbar inserted. With this technique, the rate of elongation is ideal, the time after elongation, and well as the force, is recorded on the graph paper, and the sideways lift is eliminated.

Comparison of this study with previous reports indicate some fairly similar results. Unitek chain decayed between 46% and 55%, similar to Doyle's (23) 44% after 4 weeks in vitro, and Kuster's (12) 57% after 4 weeks in vivo (extended 200%). Clearly, the in vivo conditions can cause more decay, however, quantifying of this amount by comparison between studies is difficult. The Rocky Mountain chain decayed between 17% and 31%. This is less than reported by Killiany and Duplessis (24), with 34% decay after 4 weeks in vitro (saliva), and DeGenova, et al

(2) with 39% decay after 3 weeks in vitro with temperature cycling. This discrepancy may be due to further improvements in the chain by the manufacturer, or the effects of in vitro saliva storage (rather than water) and temperature cycling. GAC chain, with a decay range of 25% to 30%, had not been tested, so no comparisons were possible.

Future elastic testing could include evaluating more brands, open versus closed chain, clear versus gray chain, effects of prestretching (which may differ with the newer materials), effects of space closure (dynamic) on the new chains at different elongations, initial force and subjective 'feel' of initial force, material degradation during storage, and more in vivo tests to substantiate or otherwise modify the results of the in vitro tests.

The ideal force system, as conceived by Sonis, et al (3), would "(1) provide optimal tooth-moving forces to elicit the desired effect; (2) be comfortable and hygienic to the patient; (3) require minimal operator manipulation and chair time; (4) require minimal patient cooperation; and (5) be economical." Elastic thread is less hygienic than chains (3,11) and requires more operator time to tie; magnets and nickel-titanium springs are costly; elastics require patient cooperation; and arch wire loops require more chair time and are less comfortable to the patient. Elastomeric chains fullfil more qualifications, although hygiene will always be a problem. Chains can provide an optimal force if the operator knows how to manipulate them. For a clinician looking for a high continuous force, either the Rocky Mountain or GAC chain would fullfil this need. By stretching the chains 4 or more times their original length, final forces exceeding 400 grams will be obtained, with only approximately 30% force decay. Unitek chain cannot achieve this. However, if low continuous forces are desired, approximately twice as many Rocky Mountain or GAC links as Unitek links will be needed to span a distance to achieve low forces making them less economical (although the 17% force decay of Rocky Mountain chain at low forces is very ideal). More importantly, if a new generation chain is used to consolidate spaces by chain ligating each tooth around the arch, the percent elongation cannot be changed and these chains may exert too much force for the operator. In addition, a dynamic study of a newer generation chain may reveal that minimally stretched chains yield more force decay with tooth movement. The dynamic study by Hershey and Reynolds (25) was somewhat suggestive of this possibility since the force loss from 24 hours to 4 weeks was greater with lower initial forces. Of the three tested, only Unitek chain can achieve very low final forces when using less chain length or ligating around an arch, however, it has a concomitantly high percent force decay of approximately 50%.

Other chains, not tested in this study, could fullfil the ideal criteria for a low and continuous force. Open chain of thinner, lighter chains may yield low forces and low percent force decay.

SUMMARY AND CONCLUSIONS

The force decay of three different brands of chain elastic was evaluated at four different elongations over four weeks, while stored in a 37 degree Celsius water bath. Care was taken to reduce variability of the chains, by minimizing cycling, eliminating drying during force measurements, and using an Instron Testing Machine to measure the forces. Suggestions were given for better measurement of the initial force which exhibited the highest variability.

Results of the study revealed:

1. Force decay is positively correlated with initial force and percent elongation.
2. Average percent force decay of the three brands were statistically different: RMO - 23%, GAC - 28%, UNI - 50%.
3. Analysis of variance revealed that percent force decay can vary with percent elongation and thus, the average percent force decay for a chain, or a percent force decay at only one elongation, may be useless for predicting its final force. RMO exhibited statistically more percent force decay with more elongation (31% compared to 17%). UNI exhibited statistically less percent force decay with more elongation (46% compared to 55%). GAC exhibited

similar percent force decay regardless of elongation (25% to 30% range).

4. Regression line equations were presented to predict final force from initial force (and vice versa) for each brand.

5. Regression line equations and a prediction table were presented for determining initial and final force from percent elongation. The differences between the brands studied appear clinically relevant.

These results indicated that RMO and GAC chains are more ideal for high continuous force mechanics, while UNI is better suited for low force mechanics. A chain suitable for low continuous force mechanics was not tested in this study, and further chain evaluations are recommended.

BIBLIOGRAPHY

1) GAC International, Inc., Product information advertisement on Super Energy Chainettes.

2) DeGenova DC, McInnes-Ledoux P, Weinberg R, Shaye R: Force degradation of orthodontic elastomeric chains - a product comparison study. Am J Orthod, 87:377-384, 1985.

3) Sonis AL, Van Der Plas E, Gianelly A: A comparison of elastomeric auxiliaries versus elastic thread on premolar extraction site closure: An in vivo study. Am J Orthod, 89:73-78, 1986.

4) Wong AK: Orthodontic elastic materials. Angle Orthod, 46:196-205, 1976.

5) Agranoff J (editor): Modern Plastics Encyclopedia, 1985-1986, McGraw-Hill, Inc., New York, New York, 1985.

6) Mod Com Inc., personal communication, 1988.

7) Andreasen GF, Bishara SE: Comparison of AlastiK chains with elastics involved with intra-arch molar to molar forces. Angle Orthod, 40:151-158, 1970.

8) Bishara SE, Andreasen GF: A comparison of time related forces between plastic AlastiKs and latex elastics. Angle Orthod, 40:319-328, 1970.

9) Brooks DG, Hershey HG: Effects of heat and time on stretched plastic orthodontic modules. J Dent Res Abstract, 55B:363, 1976.

10) Ash JL, Nikolai RJ: Relaxation of orthodontic elastomeric chains and modules in vitro and in vivo. J Dent Res, 57:685-690, 1978.

11) Howard RS, Nikolai RJ: On relaxation of orthodontic elastic threads. Angle Orthod, 49:167-172, 1979.

12) Kuster R, Ingervall B, Burgin W: Laboratory and intra-oral tests of the degradation of elastic chains. Eur J Orthod, 8:202-208, 1986.

13) Kovatch JS, Lautenschlager EP, Apfel DA, Keller JC: Load-extension-time behavior of orthodontic AlastiKs. J Dent Res, 55:783-786, 1976.

14) Young J, Sandrik JL: The influence of preloading on stress relaxation of orthodontic elastic polymers. Angle Orthod, 49:104-109, 1979.

15) Varner RE: Force production and Decay rates in AlastiK modules. Certificate Thesis, University of Oregon Health Sciences Center, 1974.

16) Varner RE, Buck DL: Force production and decay rates in Alastik modules. J Biomed, Mat Res, 12:361-366, 1978.

17) Reitan K: Some factors determining the evaluation of forces in orthodontics. Am J Orthod, 43:32-45-1957.

18) Quinn RS, Yoshikawa DK: A reassessment of force magnitude in orthodontics. Am J Orthod, 88(3):252-260, 1985.

19) Hixon EH, Atikian H, Callow GE, McDonald HW, Tacy RJ: Optimum force, differential force and anchorage. Am J Orthod, 55:437-457, 1969.

20) Paulson RC, Speidel RM, Isaacson RJ: A laminographic study of cuspid retraction versus molar anchorage loss. Angle Orthod, 40:20-27, 1970.

21) Huffman DJ, Way DC: A clinical evaluation of tooth movement along arch wires of two different sizes. Am J Orthod, 83(6):453-459, 1983.

22) Hixon EH, Aasen TO, Arango J, Clark RA, Klosterman R, Miller SS, Odom WM: On force and tooth movement. Am J of Orthod, 57:476-489, 1970.

23) Doyle L: Force Production and Decay Rate in Cl AlastiK Modules. Certificate Thesis, University of Oregon Health Sciences Center, 1979.

24) Killiany DM, Deplessis J: Relaxation of elastomeric chains. J Clin Orthod, 19(8):592-593, 1985.

25) Hershey HG, Reynolds WG: The plastic module as an orthodontic tooth-moving mechanism. Am J Orthod, 67:554-562, 1975.

26) Porter TJ: Force Production and Decay Rate in Cl AlastiK Modules with Simulated Tooth Movement. Certificate Thesis, University of Oregon Health Sciences Center, 1980.

27) Rock WP, Wilson HJ, Fisher S: Force reduction of orthodontic elastomeric chain after one month in the mouth. Brit J Orthod, 13(3):147-150, 1986.

28) Brantley WA, Salander S, Myers CL, Winders RV: Effects of prestretching on force degradation characteristics of plastic modules. Angle Orthod, 49:37-43, 1979.

29) Phillips DS: Basic Statistics for the Health Science Student. W.H. Freeman and Company, New York, 1978.

30) Boester CH, Johnston EL: A clinical investigation of the concepts of differential and optimal force in canine retraction. Angle Orthod, 44:113-119, 1974.

31) Buck DL, Church DH: A histographic study of human tooth movement. Am J Orthod, 62:507-516, 1972.

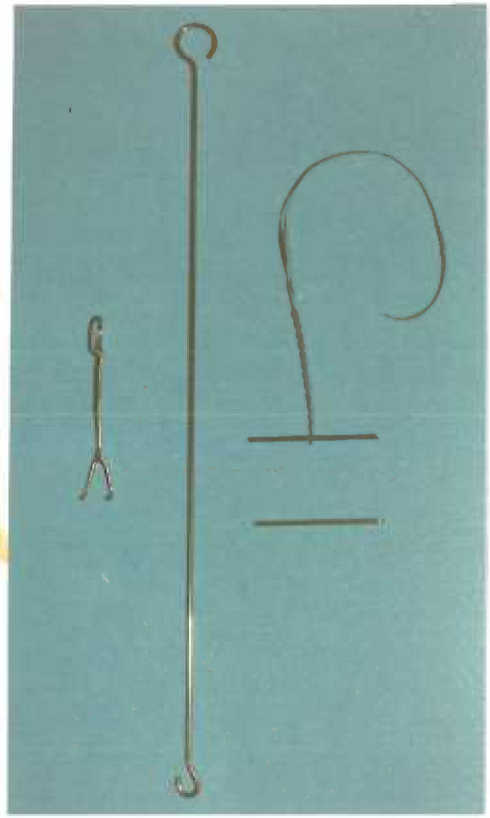

Figure 1. Test apparatus (left to right):
Lifting fork, extension fork, .062 SS wires with c-chain and string.

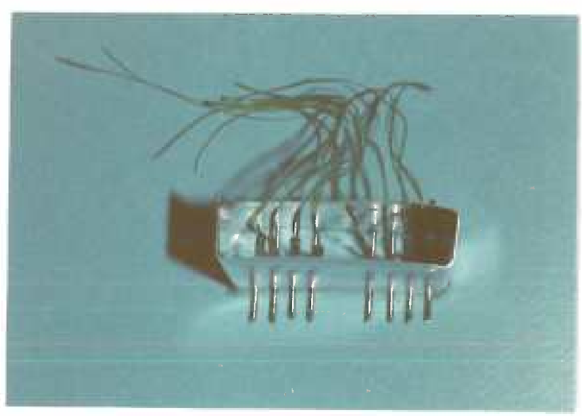

Figure 2. Aluminum jig with 8 chains on .062 SS wires.

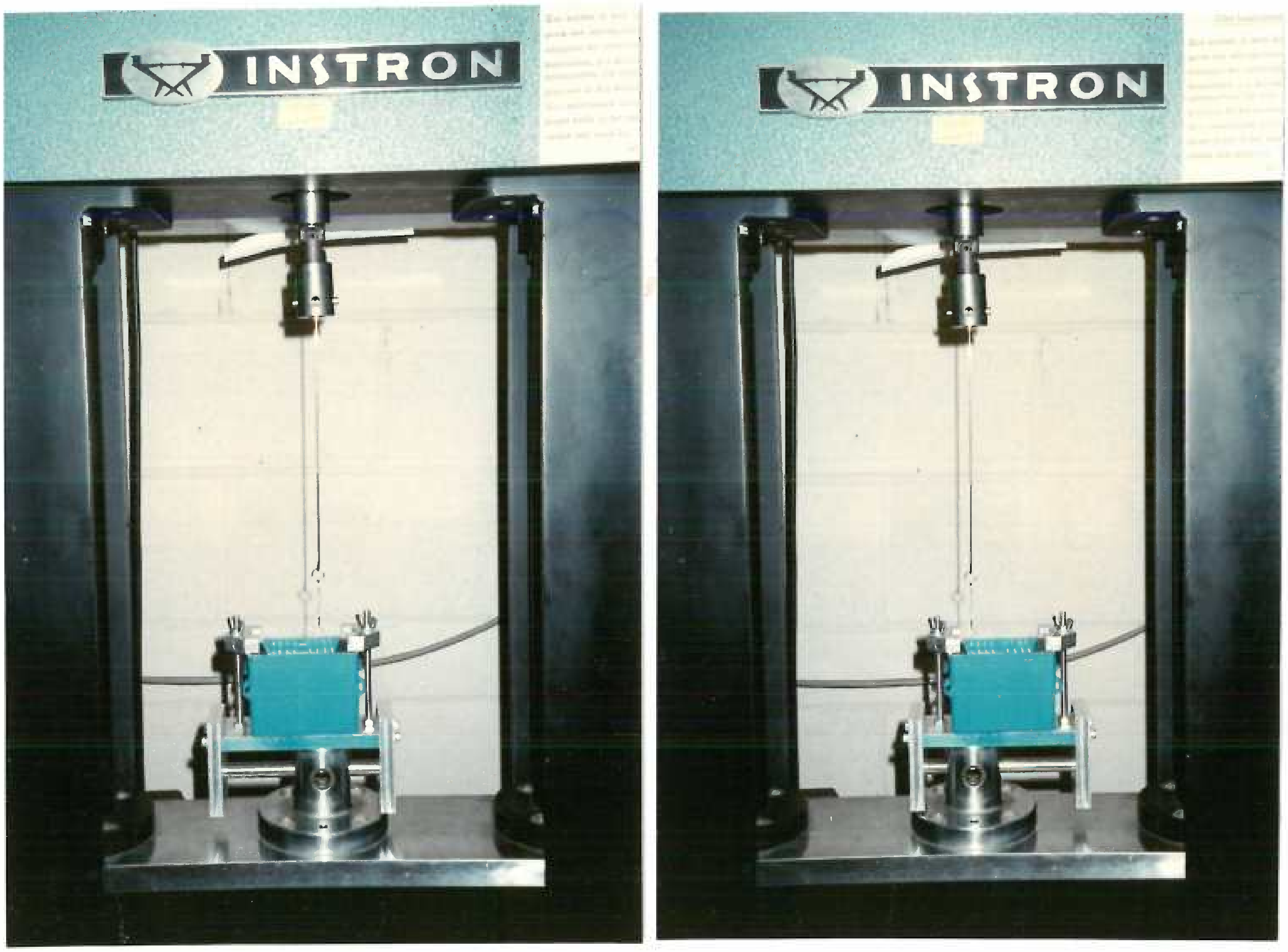

Figure 3. a. Box containing the jig mounted on the sliding platform attached to the Instron Testing Machine.

b. Sliding platform showing side-to-side movement. (Shown without water for clarity).

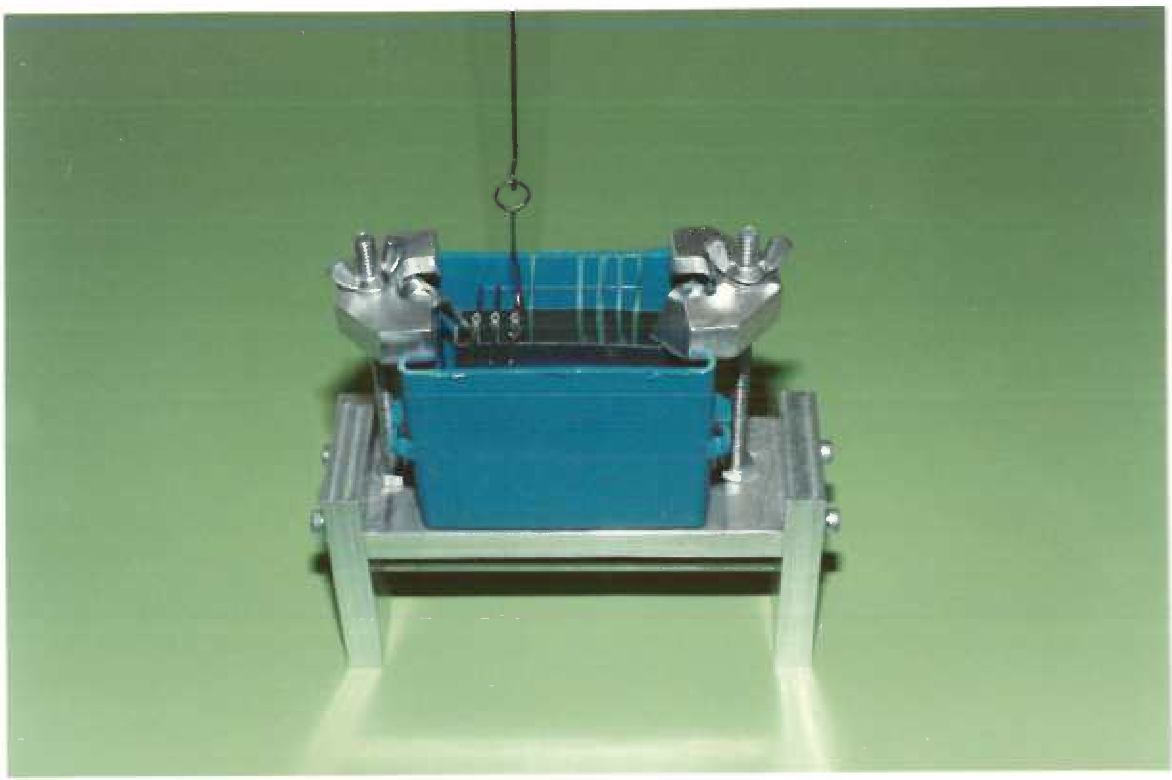

Figure 4. Lifting fork raising a chain by lifting the .062 SS wire. (Shown without water for clarity).

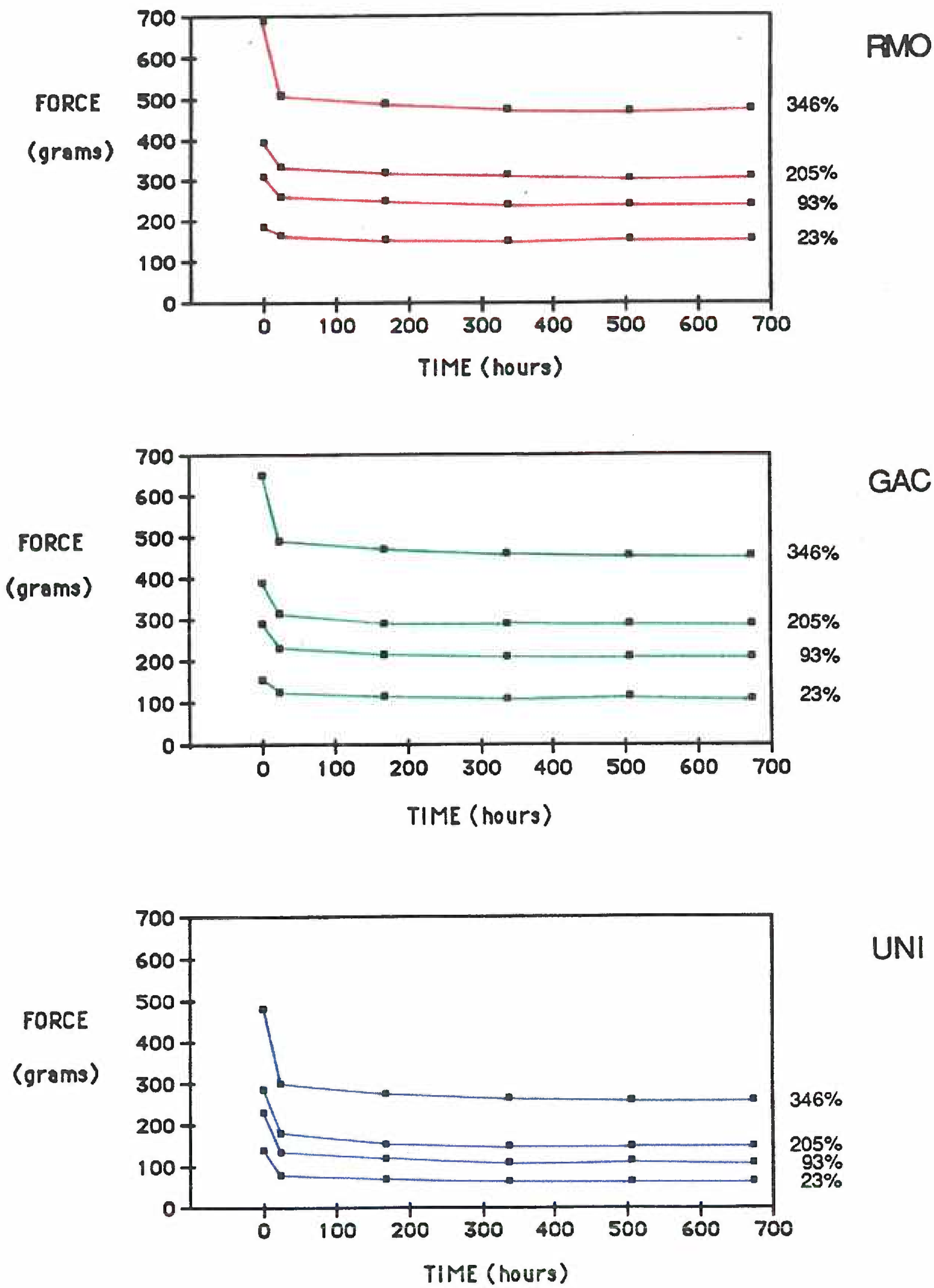

Figure 5. Effect of Time on the Force (grams) of the three brands of chain at the four different elongations.

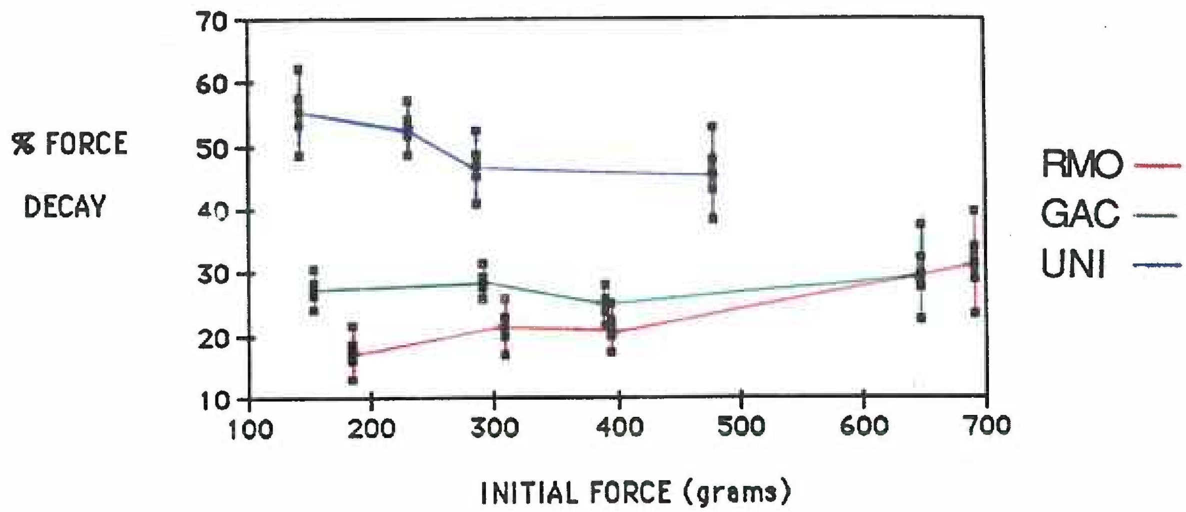

Figure 6. Percent Force Decay with varying Initial Force for the three brands.
+/- 2 Standard Deviations -- black.
+/- 2 Standard Error of the Mean -- color.

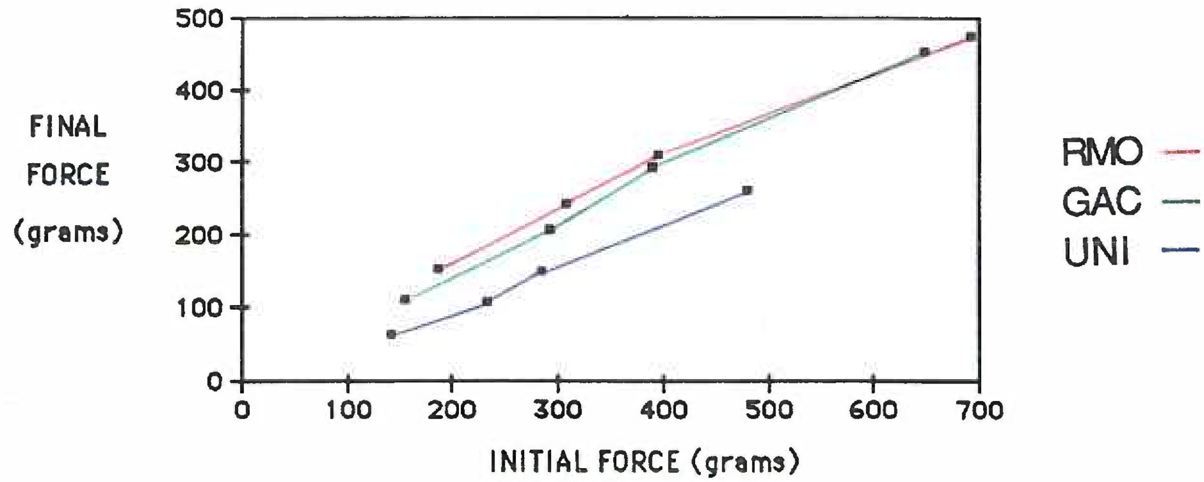

Figure 7. Relationship of Final Force to Initial Force for the three brands.

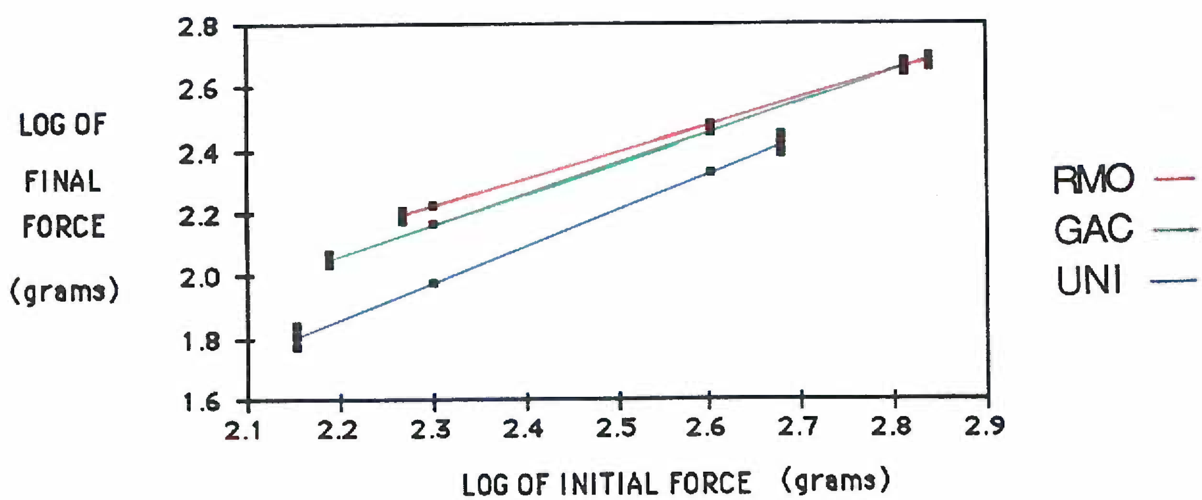

Figure 8. Regression lines of log-log transformed data of Final Force to Initial Force. The standard error of the estimate is indicated at the end of each line for the three brands.

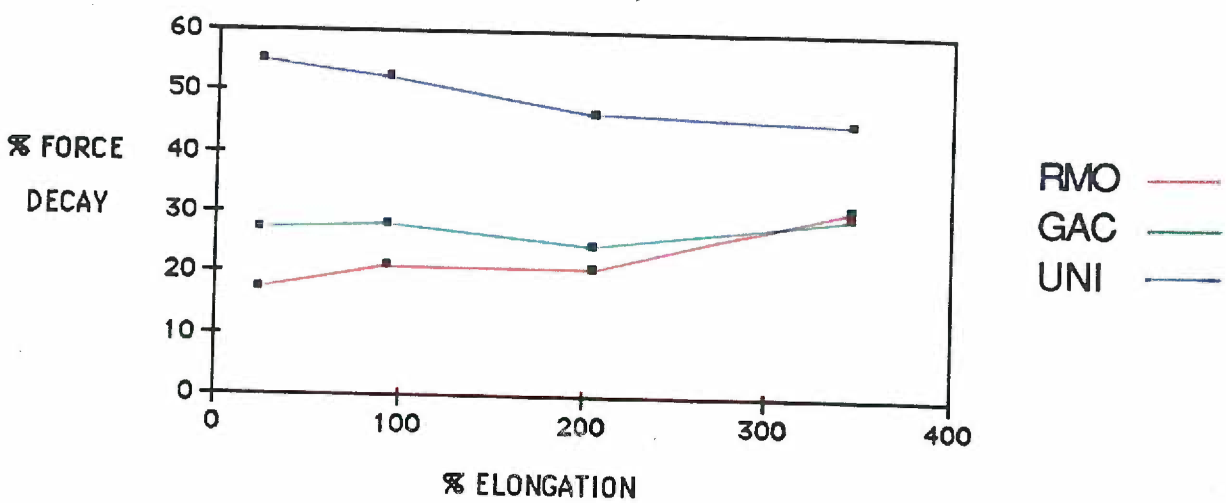

Figure 9. Effect of Percent Elongation on Percent Force Decay for the three brands.

% ELONGATION		X ORIGINAL LENGTH	RMO INITIAL	RMO FINAL	GAC INITIAL	GAC FINAL	UNI INITIAL	UNI FINAL
25%	=	1.25 x	180	160	160	120	140	60
50%	=	1.5 x	220	180	200	150	170	80
100%	=	2 x	290	230	270	200	220	110
200%	=	3 x	440	330	410	300	320	170
300%	=	4 x	590	420	560	400	420	230

Table 1. A Prediction Table for determining force (grams) resulting from various elongations, calculated from the following regression lines:

Final Force (grams) from Percent Elongation:

RMO $Y = 135.7 + 0.96X$

GAC $Y = 96.2 + 1.02X$

UNI $Y = 47.5 + 0.59X$

Initial Force (grams) from Percent Elongation:

RMO $Y = 143.9 + 1.50X$

GAC $Y = 126.6 + 1.46X$

UNI $Y = 118.9 + 0.99X$

BRAND	% FORCE DECAY	(n = 40, ordered overall means)
RMO	22.84	
GAC	27.60	contrast for alpha = .05 = 2.88
UNI	50.14	

Table 2. Results of Two-Way Analysis of Variance for Overall Means. (Means are significantly different at alpha = 0.05).

BRAND	% ELONGATION	% FORCE DECAY	(n = 10)
RMO	23%	17.37	
RMO	205%	21.18	
RMO	93%	21.47	
GAC	205%	24.78	
GAC	23%	27.35	
GAC	93%	28.40	contrast for alpha = .05 = 4.05
GAC	346%	29.85	
RMO	346%	31.32	
UNI	346%	45.54	
UNI	205%	46.78	
UNI	93%	52.89	
UNI	23%	55.35	

Table 3. Results of Two-Way Analysis of Variance for Individual Means. The numbers inside each box are statistically similar, while those outside a given box are significantly different at alpha = 0.05.

RMO

346%

	0 HOUR	24 HOURS	1 WEEK	2 WEEKS	3 WEEKS	4 WEEKS
1	757.345	516.990	498.850	476.175	476.175	476.175
2	739.205	498.850	480.710	471.640	462.570	471.640
3	666.645	526.060	498.850	485.245	480.710	480.710
4	648.505	489.780	480.710	462.570	453.500	453.500
5	639.435	498.850	471.640	467.105	467.105	476.175
6	752.810	516.990	494.315	471.640	471.640	476.175
7	680.250	516.990	498.850	494.315	480.710	480.710
8	684.785	512.455	489.780	476.175	467.105	467.105
9	684.785	521.525	485.245	480.710	471.640	476.175
10	662.110	512.455	489.780	480.710	471.640	476.175

205%

1	362.800	308.380	299.310	290.240	299.310	290.240
2	408.150	353.730	335.590	331.055	281.170	321.985
3	394.545	335.590	321.985	308.380	312.915	312.915
4	353.730	312.915	294.775	299.310	285.705	290.240
5	399.080	335.590	321.985	317.450	312.915	317.450
6	426.290	344.660	331.055	317.450	321.985	321.985
7	399.080	335.590	317.450	317.450	312.915	312.915
8	394.545	335.590	317.450	308.380	308.380	312.915
9	390.010	335.590	321.985	321.985	317.450	308.380
10	417.220	344.660	321.985	321.985	317.450	317.450

93%

1	317.450	267.565	253.960	244.890	244.890	244.890
2	317.450	263.030	253.960	244.890	240.355	240.355
3	308.380	258.495	249.425	240.355	240.355	240.355
4	272.100	244.890	240.355	226.750	231.285	226.750
5	317.450	263.030	253.960	244.890	244.890	244.890
6	308.380	258.495	249.425	235.820	235.820	240.355
7	308.380	263.030	253.960	249.425	244.890	249.425
8	321.985	263.030	249.425	249.425	249.425	249.425
9	299.310	263.030	244.890	240.355	240.355	240.355
10	303.845	258.495	244.890	231.285	235.820	235.820

23%

1	190.470	163.260	163.260	149.655	158.725	154.190
2	176.865	163.260	154.190	149.655	158.725	149.655
3	185.935	163.260	158.725	149.655	154.190	158.725
4	181.400	158.725	154.190	154.190	154.190	154.190
5	190.470	163.260	154.190	145.120	149.655	149.655
6	185.935	163.260	154.190	154.190	154.190	154.190
7	185.935	163.260	149.655	149.655	154.190	154.190
8	185.935	167.795	154.190	154.190	154.190	149.655
9	181.400	158.725	145.120	149.655	149.655	149.655
10	185.935	163.260	149.655	154.190	158.725	154.190

Table 4. Raw Data -- Force (grams) converted from pounds. Rocky Mountain Energy Chain.

GAC

346%

	0 HOUR	24 HOURS	1 WEEK	2 WEEKS	3 WEEKS	4 WEEKS
1	612.225	471.744	462.672	448.965	448.965	444.430
2	648.505	489.888	462.672	453.500	448.965	444.430
3	675.715	498.960	485.352	480.710	471.640	462.570
4	643.970	503.496	471.744	462.570	458.035	448.965
5	634.900	498.960	494.424	480.710	471.640	476.175
6	548.735	453.600	435.456	430.825	426.290	426.290
7	666.645	489.888	471.744	462.570	448.965	448.965
8	689.320	508.032	480.816	476.175	462.570	462.570
9	671.180	503.496	467.208	467.105	458.035	453.500
10	684.785	503.496	471.744	458.035	458.035	462.570

205%

	0 HOUR	24 HOURS	1 WEEK	2 WEEKS	3 WEEKS	4 WEEKS
1	399.080	321.985	299.310	290.240	294.775	294.775
2	380.940	312.915	294.775	285.705	290.240	290.240
3	380.940	321.985	308.380	285.705	299.310	294.775
4	371.870	312.915	294.775	290.240	285.705	285.705
5	385.475	321.985	308.380	299.310	294.775	294.775
6	385.475	312.915	294.775	290.240	290.240	290.240
7	403.615	321.985	308.380	303.845	299.310	299.310
8	408.150	317.450	303.845	294.775	294.775	294.775
9	385.475	312.915	290.240	285.705	285.705	290.240
10	390.010	312.915	290.240	285.705	290.240	290.240

93%

	0 HOUR	24 HOURS	1 WEEK	2 WEEKS	3 WEEKS	4 WEEKS
1	272.100	217.680	204.075	195.005	204.075	199.540
2	294.775	240.355	222.215	217.680	217.680	213.145
3	294.775	235.820	222.215	213.145	213.145	213.145
4	290.240	226.750	217.680	208.610	208.610	204.075
5	299.310	231.285	222.215	213.145	213.145	208.610
6	294.775	231.285	217.680	204.075	208.610	208.610
7	285.705	231.285	213.145	213.145	208.610	208.610
8	299.310	231.285	208.610	208.610	208.610	208.610
9	294.775	235.820	213.145	213.145	208.610	208.610
10	285.705	231.285	208.610	208.610	208.610	208.610

23%

	0 HOUR	24 HOURS	1 WEEK	2 WEEKS	3 WEEKS	4 WEEKS
1	154.190	126.980	122.445	108.840	117.910	113.375
2	154.190	122.445	117.910	113.375	108.840	108.840
3	158.725	126.980	122.445	113.375	117.910	113.375
4	149.655	122.445	117.910	108.840	113.375	113.375
5	154.190	122.445	117.910	108.840	108.840	108.840
6	158.725	126.980	117.910	113.375	113.375	117.910
7	149.655	122.445	113.375	108.840	113.375	108.840
8	154.190	122.445	108.840	104.305	113.375	113.375
9	149.655	122.445	113.375	108.840	108.840	108.840
10	158.725	126.980	108.840	113.375	113.375	113.375

Table 5. Raw Data -- Force (grams) converted from pounds. GAC Chainette.

346%

	0 HOUR	24 HOURS	1 WEEK	2 WEEKS	3 WEEKS	4 WEEKS
1	489.780	294.775	272.100	272.100	272.100	263.030
2	566.875	312.915	290.240	276.635	272.100	272.100
3	430.825	290.240	263.030	253.960	249.425	249.425
4	476.175	294.775	272.100	249.425	253.960	244.890
5	471.640	317.450	294.775	281.170	276.635	276.635
6	503.385	299.310	276.635	263.030	258.495	258.495
7	485.245	294.775	285.705	267.565	267.565	263.030
8	489.780	299.310	276.635	267.565	258.495	258.495
9	444.430	294.775	263.030	267.565	258.495	258.495
10	435.360	294.775	263.030	258.495	253.960	253.960

205%

	0 HOUR	24 HOURS	1 WEEK	2 WEEKS	3 WEEKS	4 WEEKS
1	308.380	176.865	158.725	145.120	154.190	154.190
2	317.450	185.935	158.725	149.655	154.190	154.190
3	258.495	172.330	154.190	136.050	145.120	145.120
4	267.565	167.795	158.725	145.120	140.585	140.585
5	272.100	185.935	163.260	154.190	154.190	158.725
6	281.170	176.865	149.655	140.585	158.725	149.655
7	267.565	176.865	154.190	145.120	149.655	145.120
8	294.775	172.330	149.655	149.655	149.655	149.655
9	294.775	185.935	163.260	158.725	158.725	158.725
10	290.240	185.935	158.725	158.725	154.190	158.725

93%

	0 HOUR	24 HOURS	1 WEEK	2 WEEKS	3 WEEKS	4 WEEKS
1	213.145	122.445	108.840	99.770	104.305	95.235
2	235.820	136.050	122.445	108.840	113.375	108.840
3	235.820	136.050	122.445	108.840	113.375	108.840
4	222.215	140.585	122.445	108.840	117.910	113.375
5	222.215	136.050	122.445	104.305	113.375	108.840
6	231.285	136.050	122.445	104.305	113.375	108.840
7	235.820	136.050	117.910	117.910	113.375	113.375
8	231.285	136.050	113.375	113.375	113.375	108.840
9	235.820	140.585	117.910	117.910	113.375	113.375
10	249.425	140.585	117.910	108.840	113.375	108.840

23%

	0 HOUR	24 HOURS	1 WEEK	2 WEEKS	3 WEEKS	4 WEEKS
1	149.655	86.165	77.095	63.490	72.560	68.025
2	145.120	81.630	68.025	63.490	68.025	58.955
3	145.120	86.165	72.560	58.955	63.490	68.025
4	140.585	77.095	68.025	58.955	68.025	58.955
5	145.120	77.095	68.025	63.490	63.490	58.955
6	136.050	77.095	68.025	68.025	68.025	63.490
7	131.515	77.095	63.490	58.955	68.025	68.025
8	140.585	81.630	63.490	63.490	63.490	63.490
9	136.050	81.630	68.025	58.955	63.490	58.955
10	154.190	86.165	68.025	68.025	68.025	68.025

Table 6. Raw Data -- Force (grams) converted from pounds. Unitek Alastik Spool Chain.

FORCE (grams)
(S.D., S.E.M.)

BRAND	% ELONGATION	0 HOURS	24 HOURS	ONE WEEK	TWO WEEKS	THREE WEEKS	FOUR WEEKS
RMO	23	185.0 (4.2,1.3)	162.8 (2.6,0.8)	153.7 (5.0,1.6)	151.0 (3.1,1.0)	154.6 (3.3,1.1)	152.8 (3.1,1.0)
	93	307.5 (14.3,4.5)	260.3 (6.1,1.9)	249.4 (4.8,1.5)	240.8 (7.5,2.4)	240.8 (5.4,1.7)	241.3 (6.7,2.1)
	205	394.5 (22.2,7.0)	334.2 (13.9,4.4)	318.4 (12.6,4.0)	313.4 (12.0,3.8)	307.0 (13.9,4.4)	310.6 (11.6,3.7)
	346	691.6 (43.0,15.6)	511.1 (11.5,3.6)	488.9 (9.3,2.9)	476.6 (9.2,2.9)	470.3 (8.3,2.6)	473.5 (8.1,2.5)
GAC	23	154.2 (3.7,1.2)	124.3 (2.3,0.7)	116.1 (4.8,1.5)	110.2 (3.1,1.0)	112.9 (3.3,1.1)	112.0 (3.1,1.0)
	93	291.1 (8.2,2.6)	231.3 (6.0,1.9)	215.0 (6.5,2.1)	209.5 (6.3,2.0)	210.0 (3.7,1.2)	208.2 (4.0,1.3)
	205	389.1 (11.3,3.6)	317.0 (4.5,1.4)	299.3 (7.4,2.3)	291.1 (6.3,2.0)	292.5 (4.9,1.5)	292.5 (3.8,1.2)
	346	647.6 (42.2,13.3)	492.2 (17.1,5.4)	470.4 (15.9,5.0)	462.1 (15.5,4.9)	455.3 (13.2,4.2)	453.0 (13.7,4.4)
UNI	23	142.4 (6.8,2.2)	81.2 (3.9,1.3)	68.5 (4.0,1.3)	62.6 (3.6,1.1)	66.7 (3.1,1.0)	63.5 (4.3,1.4)
	93	231.3 (10.0,3.2)	136.1 (5.2,1.7)	118.8 (4.7,1.5)	109.3 (5.8,1.8)	112.9 (3.3,1.1)	108.8 (5.2,1.7)
	205	285.3 (19.1,6.1)	178.7 (6.8,2.2)	156.9 (4.9,1.5)	148.3 (7.4,2.3)	151.9 (5.7,1.8)	151.5 (6.5,2.1)
	346	479.4 (39.5,12.5)	299.3 (8.8,2.8)	275.7 (11.5,3.6)	265.8 (9.8,3.1)	262.1 (9.3,2.9)	259.9 (9.6,3.0)

Table 7. Descriptive Statistics of Force (grams) - Means (n = 10) Standard Deviations and Standard Error of the Means are given in parentheses below each Mean.

% FORCE DECAY					
% ELONGATION	346%	205%	93%	23%	
	37.1	20.0	22.9	19.0	RMO
	36.2	21.1	24.3	15.4	RMO
	27.9	20.7	22.1	14.6	RMO
	30.1	17.9	16.7	15.0	RMO
	25.5	20.5	22.9	21.4	RMO
	36.7	24.5	22.1	17.1	RMO
	29.3	21.6	19.1	17.1	RMO
	31.8	20.7	22.5	19.5	RMO
	30.5	20.9	19.7	17.5	RMO
	28.1	23.9	22.4	17.1	RMO
$\overline{X}$	31.3	21.2	21.5	17.4	RMO
S.D.	4.1	1.9	2.3	2.1	RMO
S.E.M.	1.3	0.6	0.7	0.7	RMO
	27.4	26.1	26.7	26.5	GAC
	31.5	23.8	27.7	29.4	GAC
	31.5	22.6	27.7	28.6	GAC
	30.3	23.2	29.7	24.2	GAC
	25.0	23.5	30.3	29.4	GAC
	22.3	24.7	29.2	25.7	GAC
	32.7	25.8	27.0	27.3	GAC
	32.9	27.8	30.3	26.5	GAC
	32.4	24.7	29.2	27.3	GAC
	32.5	25.6	27.0	28.6	GAC
$\overline{X}$	29.9	24.8	28.5	27.4	GAC
S.D.	3.7	1.6	1.4	1.7	GAC
S.E.M.	1.2	0.5	0.4	0.5	GAC
	54.5	55.3	50.0	46.3	UNI
	59.4	53.8	51.4	52.0	UNI
	53.1	53.8	43.9	42.1	UNI
	58.1	49.0	47.5	48.6	UNI
	59.4	51.0	41.7	41.3	UNI
	53.3	52.9	46.8	48.6	UNI
	48.3	51.9	45.8	45.8	UNI
	54.8	52.9	49.2	47.2	UNI
	56.7	51.9	46.2	41.8	UNI
	55.9	56.4	45.3	41.7	UNI
$\overline{X}$	45.5	46.8	52.9	55.4	UNI
S.D.	3.7	2.9	2.1	3.4	UNI
S.E.M.	1.2	0.9	0.7	1.1	UNI

Table 8. Percent Force Decay (of the three brands at four different elongations):

(Initial Force - Final Force) / Initial Force

$\overline{X}$ = Mean

S.D. = Standard Deviation

S.E.M. = Standard Error of the Mean