FORCE PRODUCTION AND DECAY RATE IN C1 ĀLASTIK MODULES

Larry M. Doyle, D.D.S.

This paper submitted in partial fulfillment of the
requirements for a Certificate in Orthodontics,
University of Oregon Dental School.

June 1979

ACKNOWLEDGMENTS

I thank the following individuals; each has provided assistance during the research and preparation of this paper:

Dr. Douglas L. Buck, Professor and Chairperson,
Department of Orthodontics.

Dr. Paul E. Klein, Clinical Associate,
Department of Orthodontics.

Ms. Kathy Jenson, Secretary,
Department of Orthodontics.

Dr. David B. Mahler, Professor and Chairperson,
Department of Dental Materials Science.

Mr. Richard L. Marantz, Research Assistant and Statistician,
Department of Dental Materials Science.

Mr. Lyle Nelson, Research Assistant,
Department of Dental Materials Science.

Mr. Gary Cantwell, Research Assistant,
Department of Dental Materials Science.

Dr. Morris E. Weaver, Professor,
Department of Anatomy

Ms. Fran Miller, Histology Technician,
Tissue Lab.

My family . . . Gail, Michael, and Kristin.

TABLE OF CONTENTS

INTRODUCTION

Crowded front teeth is a common reason why people seek orthodontic treatment. Extraction of premolar teeth, especially first premolars, is frequently part of the treatment plan since the Tweed[1] articles in the 1940's. This concept involves providing space to align the anterior teeth. Once extraction space has been created, there is very often a need for distal retraction of the permanent cuspids in order to bring the crowded teeth into the arch.

Various methods for cuspid retraction have been used including open coil springs, retraction springs, latex elastics, and more recently ĀlastiK* modules and J-hook headgear. Each method has advantages and disadvantages according to the "philosophy" of the orthodontist. The type of ĀlastiK module used for retraction along with the method of application is also varied among orthodontists.

ĀlastiK "C" chain plastic modules placed buccal and lingual from molar to cuspid have been recommended for this purpose[2,24]. With the rings of the buccal chain engaging the brackets as illustrated by Unitek[3], the module also functions to hold the bracket wings to the arch wire. Buttons or cletes provide attachments for the lingual chain. In addition to cuspid retraction, space can be consolidated in this manner and

---

* ĀlastiK is a trade name for an elastomer of polyurethane resin that is isocyanate terminated and marketed by Unitek Corporation of Monrovia, CA.

reciprocal force can be utilized.

Previous published studies[4-12] have given an insight into the properties and behavior of ĀlastiKs. The different modules have been stretched various distances under different conditions. Except for one in vivo study[11], plastic modules have not been examined by that research under simulated clinical usage. The modules have been stretched through space to predetermined "typical" distances.

The purpose of this investigation is to: 1) quantify the force produced by C1 chain ĀlastiK modules when used for cuspid retraction across an "average" extraction site and 2) determine the rate of force decay of C1 chains at selected time intervals up to four weeks under simulated clinical conditions utilizing bands, brackets, and arch wires.

REVIEW OF THE LITERATURE

ĀlastiKs were introduced to the profession in the late 1960's. They were made of a clear polyurethane plastic and were offered in various shapes and sizes. The different modules were recommended for different "mechanics" purposes and were available in a regular and a heavy force material*. Clinical observations revealed that after a three to four week interval, the ĀlastiKs were permanently elongated a large amount when compared to their original size. There also appeared to be little force left in the module after this time period. In addition to the deformation, ĀlastiKs showed varying degrees of discoloration clinically with time. Their long-term effectiveness and the force ranges that they produce at various distances and time intervals was unknown to the clinician.

The first study of ĀlastiKs to appear in the literature was that of Andreasen and Bishara[4] in 1970. Two separate articles were published in July and October of that year. In the first article, they reported results of a pilot study of simulated mouth conditions on 100 clear C1 ĀlastiK chains. Using "t" tests, they showed that there is no statistical difference between test conditions when ĀlastiK modules are tested in 37° C. water or 37° C. saliva. They did find that when the material was tested dry at room temperature, there is a statistically significant difference from body temperature

---

* ĀlastiK modules with grey color inclusions added to the polyurethane resin were made available in 1971[13].

saliva. Water at 37° C. has been used for most tests on Ālastiks since this study.

In addition to the pilot study, Andreasen and Bishara stretched 100 C1 chain ĀlastiKs five different distances ranging from 65 mm to 105 mm. They tested both regular and heavy clear force material on wire frames at the specified elongation for each time interval of measurement. They found a mean force decay of 74.2 (±5.8)% in 24 hours. The greatest force decay per unit time was during the first hour, 55.7 (±6.7)%. The remaining rate of decay for 3 weeks was 8.2 (±4.1)% for a total force loss of about 82% . The heavy clear material had an initial stronger force, but after 8 hours the force values for heavy chains were lower than the regular chains.

At a distance of 65 mm, the regular clear C1 chains (N = 10 per stretch) had a mean force of 263 (±24.3) gm initially. In 1 hour, the mean force was 170 (±12.1) gm. At 24 hours, the force decreased to 129 (±11.1) gm and at 3 weeks, it was 97 (±10.5) gm. The regular chains at a stretch of 105 mm had an initial mean force of 420 (±21.4) gm. At 1 hour, the force was 263 (±16.7) gm. It was 215 (±11.6) gm after 24 hours and at 3 weeks, it was 154 (±13.1) gm. They note that at the maximum 105 mm elongation, the ĀlastiK C1 chains were permanently deformed by approximately 50% of their original length. The amount of this permanent deformation increased with time and the less the original stretch, the less percentage deformity occurred.

In their second article, Bishara and Andreasen[5] studied 90 regular K1, heavy K2, and regular K3 clear ĀlastiK modules as used for Class II and Class III mechanics. They stretched the modules on a stepped aluminum sheet with distances ranging from 22 mm to 40 mm between steps. They found that the mean force decay for K series ĀlastiKs was 45.3% after 1 hour, 54.7% in 24 hours, and 67.5% after 3 weeks. The mean force decay was 12.8% from 1 day to 3 weeks. The heavy force material $\bar{A}$lastiKs were again found to have a higher initial force than the regular material. However, the heavy K2 lost more force and had less force than the regular material for both relative and absolute force values.

At an elongation of 22 mm, the initial mean force of 10 regular clear K1 modules was 476 ($\pm$39.0) gm. After 1 hour, the mean force was 310 ($\pm$43.0) gm. It was 285 ($\pm$54.8) gm in 24 hours and it was 194 ($\pm$44.7) gm after 3 weeks. Ten regular clear K1 $\bar{A}$lastiKs stretched 40 mm had an initial mean force of 1170 ($\pm$90.0) gm. The mean force was 577 ($\pm$114.0) gm after 1 hour. It was 462 ($\pm$130.4) gm in 24 hours and after 3 weeks, it was 380 ($\pm$97.6) gm. Bishara and Andreasen point out that if the $\bar{A}$lastiK material is removed from the wet environment and allowed to dry out, the force increased.

In 1971, Ware[6] presented results of a study by the Australian Commonwealth Bureau of Dental Standards. In one of their investigations, they soaked regular clear C2 $\bar{A}$lastiK chains for 4 hours in water at 37^{o} C. and then tested one of the chains for Tension Set. This is a standard test for measuring the plastic flow in a material. The C2 $\bar{A}$lastiK was stretched to a load of 500 gm of force and held at that distance for 10 minutes. A load cell registered the decrease in force exerted by the material. After the 10 minutes, the force of the chain decreased by 200 gm. The load was then reduced to zero. The module was appreciably deformed when compared to its original length.

Hershey and Reynolds[7] (1975) reported data describing the behavior of plastic modules when the stretch distance is decreased at rates of 0.25 mm and 0.50 mm per week (simulated tooth movement). They tested a total of

540 plastic modules consisting of Ālastik regular clear C1 chains, Ālastik grey cut spool chain, Ormco Power Chain and Links, and TP Elast-O Chain. Edgewise brackets were welded to a stainless steel framework on which the modules were elongated a distance ranging from 12 mm to 34 mm. The brackets were welded in groups of 10 at the same separation with the framework closed weekly. The framework with the test modules was kept in 37^{o} C. water.

They calculated the mean rate of force decay from a sample consisting of specimens of all four types of modules held at a constant stretch for each measurement distance. The average decrease in force was 36% after 1 hour, 53% after 24 hours, and 58% in 6 weeks. When the stretch distance was decreased at the rate of 0.25 mm per week, the mean force of the modules decreased 68% in 4 weeks and 72% after 6 weeks. At a closure rate of 0.50 mm per week, 75% of the force was lost in 4 weeks and 82% after 6 weeks.

At a fixed distance, the mean force decay from 24 hours to 6 weeks was 5%. It was 19% at the 0.25 mm per week rate of closure and it was 29% with a decrease in distance of 0.50 mm per week. From 24 hours to 4 weeks, the average force decay of the modules was 15% and 22% with decreases in stretch distance of 0.25 mm and 0.50 mm per week, respectively.

The modules produced by the three different manufacturers exhibited similar force decay curves and were judged by the investigators to be clinically equivalent. Ālastiks retained more of their initial force after 24 hours than did Power Chains or Elast-O Chains; however, the force retained at 4 weeks was very similar.

A study by Wong[8] of regular clear C2 Ālastik chains was published in 1976. He used stainless steel plates on which a series of edgewise brackets were welded 17 mm apart. The 17 mm distance represented the average interbracket distance between the cuspid and second premolar. Double-ring sections were cut from the C2 chains and stretched between the brackets 10 at a time. The plates were immersed in a 37^{o} C. water bath. The samples were removed from the plates and placed on a bench force gauge testing device for measuring. The samples were restretched to 17 mm and the force value recorded.

Wong[8] found that the double-loop sections had a mean force decay of 73% in 24 hours. At 3 weeks, the average force loss was 79%; a decrease of 6% from 24 hours to 3 weeks. The initial mean force at the stretch of 17 mm was 641 gm. After 24 hours, the average force of the ĀlastiK C2 samples decreased to 171 gm.

Kovatch and others[9] (1976) report from their investigations that to slow down the rate of stress relaxation and to keep a high level of loading for an extended period of time, ĀlastiKs should be stretched slowly to position. They tested 50 regular clear K2 modules on an Instron testing machine. Original room temperature specimens were stretched to breaking at cross-head speeds of 0.2, 2, and 20 inches per minute. Other samples were soaked in 37^{o} C. saliva for 1 week. They were then stretched exactly 1 inch at the three different cross-head speeds and were maintained several weeks at a constant deformation.

Kovatch[9] found that there was a crossover with respect to testing speed that eventually leads to the more slowly stretched specimens being the strongest at breakage. In addition, specimens that were deformed with a faster speed, were stronger on stopping at the 1 inch extension. Subsequently, the force of these samples fell off more rapidly at the constant 1 inch extension than did the more slowly deformed specimens.

The Kovatch[9] group suggests that because the initial load decay is more rapid for both faster extension and higher load, care should be taken by the clinician to stretch the modules slowly into place. This should result in a higher load level for a longer period of time. They add, however, that the clinician should be aware that by doing so, he is probably forestalling the inevitable force decrease by a few hours at most.

Varner and Buck[10] (1978) tested regular clear KX-2 ĀlastiK modules in 2 mm increments from 26 mm to 40 mm at a fixed stretch. Measurements were obtained on 40 patients undergoing space closure to obtain the range of module elongation (from the distal of the molar tube or bracket to the arch wire hook mesial of the cuspid). This range proved to be 28.0 - 38.6 mm, with a mean of 34.5 mm. The KX-2 modules were held at a constant elongation on brass jigs in a 37^{o} C. water bath. Force measurements were made with an Instron testing instrument. Measurements were made on 8 elongations, with 10 KX units per elongation for a sample size of 80.

Regression lines based on the relationship of force being applied by the modules at the various initial elongations vs. log times were plotted. An analysis of covariance was performed on the regression lines and no difference (99% confidence level) was found in the slopes. The authors state that this constancy of slope indicates that the KX-2 modules tested had the same decay rate regardless of the initial elongation used. The average force decay was 26% from 2 hours to 4 weeks. They report that for the 26 mm elongation, the mean force was 1.1 lb (499 gm) at 2 hours and 0.8 lb (363 gm) at 4 weeks. For the 40 mm elongation, the mean force was 1.7 lb (771 gm) at 2 hours and 1.3 lb (590 gm) at 4 weeks. Initial force values were not reported.

In 1978, Ash and Nikolai[11] quantified the relaxation patterns of medium grey CK ĀlastiK chains and regular clear K1 ĀlastiK modules both in vitro and in vivo. The in vitro testing was done on stainless steel jigs with brass wire spurs soldered 28 mm apart. The samples were kept in 37° C. water and force magnitude data was obtained with a Chatillon spring-tension gauge. Four-unit segments of CK chain were tested along with K1 modules in subsamples of 15 specimens.

Testing in vivo was done on 5 males and 6 females, ranging in age from 11.5 to 13.2 years; all were in the initial stages of active orthodontic treatment. The chain segments and the K1 modules were stretched from the second molar to the cuspid. Chains and modules were located on opposite sides of the arch and where 4 specimens were worn, differing elements were also above and below one another on the same side. The samples were removed from their environment to take force readings for both the in vivo and the in vitro testing.

The force decay in the oral environment became statistically greater than that in 37° C. water after 1 day for the CK chain and after approximately 10 days for the K1 module. The initial mean force for the CK chain in 37° C. water was 624 ($\pm$69) gm and the average force was 209 ($\pm$29) gm after 3 weeks (a 67% force decay rate). In vivo, the initial mean force for the CK chain was 630 ($\pm$152) gm and after 3 weeks, the average force was 158 ($\pm$37) gm (a 75% force decay rate). The mean force in water after 24 hours was 264 ($\pm$37) gm (a 58% decay rate) and the force decreased another 9% over 3 weeks. After 24 hours, the average force of the chain in vivo was 245 ($\pm$59) gm (a decay of 61%). The force continued to decrease 14% over 3 weeks.

In water, the K1 modules had an initial mean force of 693 ($\pm$137) gm. The mean force in 24 hours was 290 ($\pm$68) gm and after 3 weeks, it was 236 ($\pm$58) gm. The average force decay was 58% after 24 hours and the force decreased another 8% from 24 hours to 3 weeks. The K1 modules in vivo had a mean force of 694 ($\pm$102) gm initially. In 24 hours, the average force was 293 ($\pm$77) gm and it was 193 ($\pm$40) gm after 3 weeks. The average decay rate in vivo was also 58% after 24 hours and the force decreased 10% from 24 hours to 3 weeks. The data gives the impression that the differences between relaxation in 37° C. water and in the true oral environment may be greater for the grey CK than the regular K1 Ālastiks; however, analysis-of-variance showed this interaction to be non-significant.

The influence of preloading on Ālastiks was presented by Young and Sandrik[12] in 1979. They tested medium grey CK and medium grey C2 chains on an Instron testing machine. A four-ring section of chain was used for each test sample. A sliding apparatus was constructed to prestretch the chains. The CK samples were stretched to 14 mm and 23 mm. The C2 samples were stretched to 18 mm, 36 mm, and 48 mm.

Five specimens were randomly selected for each experiment and all of the chains were stored in 37° C. water during testing. Control specimens of both CK and C2 chains were loaded to 90 gm or 0.2 lb on the Instron. The CK control showed an average force decrease of 36.6% after the first hour and the force decreased 56.4% in 24 hours. By comparison, the CK samples prestretched to 14 mm and then loaded to 90 gm on the Instron exhibited a mean force decay after 24 hours of 49%. The CK specimens prestretched to 23 mm and then loaded on the Instron showed an average force decay of 45.2% after 24 hours. Both prestretched groups showed improvement over the CK control.

The C2 control samples showed an average force decay of 31.4% in 1 hour with an initial load of 90 gm. This decreased to 43.6% after 24 hours. When prestretched to 18, 36, and 48 mm, the C2 chains exhibited a mean force decay after 24 hours of 42.8%, 43%, and 47.3%, respectively. There was no statistical difference between the medium grey C2 control and its prestretched samples.

"T" tests were used to evaluate the statistical significance between the control and the different experimental groups. At a 99% confidence limit, both groups of prestretched CK samples were found to exhibit a statistically significant increase in force over the CK control. At a 95% confidence limit, stretching CK's to 23 mm showed a significantly greater force remaining compared with samples stretched to 18 mm. The authors used semilog regression analysis to predict the amount of force that would be remaining at the end of 3 to 4 weeks for all samples tested. They predict that the CK control modules would have 21% of their force remaining after 4 weeks; whereas, the samples prestretched 18 mm would have 34.5% of their force remaining and the samples prestretched 23 mm would have 40.6% of their force remaining after 4 weeks.

As part of their study, Young and Sandrik[12] subjected another group of medium grey C2 chains to a higher initial load of 180 gm without prestretching. These C2 modules exhibited a mean force decay of 51.2% after 24 hours. Comparatively, the 90 gm initial load control group of C2 modules had an average force decay of 43.6% after 24 hours. At a 95% confidence limit, the effect of 100% increase in initial force resulted in significantly greater force decay than the control. This is in contrast to Hershey and Reynolds[7] who thought that the rate of force loss was similar whether the plastic chains that they studied were stretched to high or to low initial forces. This is also in contrast to Varner and Buck[10] who showed that the decay rate in Ālastik KX-2 plastic modules was the same regardless of the elongation and initial force magnitude.

MATERIALS AND METHODS

ĀlastiK C1 chain modules are available from the manufacturer in Regular Clear, Medium Grey, and Heavy Clear force material. Medium Grey C1 chains were selected for this study. A package of 100 chains from a fresh batch of the injection-molded modules was supplied by the manufacturer. Each C1 chain consists of 12 rings with short filaments between (Fig. 1). The 12 rings were cut into sections of 4 rings. In order to obtain a representative sample, the 4 rings were cut from different portions of a continuous chain. Randomization was accomplished by cutting the first ring from a chain; then, the remainder of the chain was cut into sections of four. Two rings were cut from the next chain and discarded. The remainder of the chain was cut into sections of four. Three rings were cut from the next chain, discarded, and so on. This process was continued through the batch of C1 chains.

In order to quantify the retraction force on a cuspid when ĀlastiK chains are attached, a series of ten test models were constructed (Fig. 2). Each model consisted of a simulated "strap-up" with two molar bands, a second premolar band, a 7 mm first premolar extraction site*, and a cuspid band mounted on a 10 cm x 10 cm base cut from 1/4 inch plexiglass. The bands were commonly used sizes containing standard twin brackets

---

* The average mesio-distal width for the first premolar of 500 North American white children is 6.9 mm (from Horowitz and Hixon[14]).

and a second molar tube with a hook. The molar bands were Unitek #35½, the premolar band was Unitek #24, and the cuspid band was Unitek #10+. Each band contained a lingual button as placed by the manufacturer.

The cuspid band was attached with orthodontic resin to a movable 1/4 inch plexiglass arm. The arm was 1 cm wide and 7 cm long. It was mounted on the base at a 60^{o} angle to a 1/4 inch plexiglass table on which the molar and premolar bands were secured. The table was 1.5 cm wide and 6 cm long. The purpose of this plexiglass table beneath the posterior bands was to elevate the bands to the height of the cuspid band and to provide a stop for the movable arm. An 11/64 inch hole was drilled in the movable arm 5.5 cm from one of the ends of the arm. After orienting the arm 60^{o}, a 5/32 inch hole was drilled into the plexiglass base. In this manner, an 8/32 machine bolt slid freely through the arm, but had to be threaded through the base. The bolt was tightened to hold the arm securely and then backed off slightly so that the arm would move freely. The movable arm would only lift slightly from the base. The bolt was secured beneath the base with two machine nuts to prevent it from turning.

To place the bands on the test models, they were first held on a .021 x .025 arch wire with A1 modules. Ideal bends had previously been placed in the arch wire. A premolar band 7 mm wide and filled with acrylic was used to provide the simulated extraction site in each of the models. The five bands were oriented visually with the posterior bands on the table, the cuspid band on the arm, and the 7 mm premolar band over the space between the table and arm. The four bands, excluding the 7 mm band, were filled with clear orthodontic resin in order to attach them to the model. This visual orientation was done on each model to closely approximate the first model. The .021 x .025 arch wire was removed after the resin was set and reused to orient the bands on the next model. A small screw eye was imbedded in the resin of the cuspid band for attachment of a measuring device.

The four-ring sections of C1 chain ĀlastiKs were thoroughly mixed and selected at random. The modules were tested two at a time with one chain stretched from second molar hook to molar bracket to premolar bracket and then across the simulated 7 mm extraction site to the distal wing of the cuspid bracket (Fig. 3). A second chain was stretched from second molar lingual button to first molar button to premolar button and then across the 7 mm extraction site to the cuspid button (Fig. 4). This is the method of cuspid retraction described by Anderson[2].

A .019 x .025 arch wire was bent for each of the ten test models. There was enough clearance for the wire to slide easily into the brackets. The buccal C1 chain was stretched over the arch wire with each ring circling the bracket to hold the wire in place as in a clinical situation (Fig. 5).

A Chatillon dial push/pull gauge (model DPP) was used to obtain force data on the cuspid band. The gauge was scaled in 10 gm graduations with a capacity of 1.0 Kg. It was calibrated with standard weights before and after the investigation and found to be accurate within one graduation or 10 gm. The gauge was furnished with a hook attachment that fit within the eye secured to the cuspid bracket. The measuring device was fastened to an 8 x 10 inch piece of 3/4 inch plywood. The plywood mount was secured horizontally on a counter top with a "C" clamp. The needle of the gauge is sensitive to gravity and the dial is adjusted to zero once the gauge is in place. A magnetically activated clutch, controlled by a switch button, allows the instrument to hold maximum readings.

At room temperature, two of the C1 chain sections were placed on each of the ten test models as described. The eye attached to the cuspid band was placed over the hook on the gauge. The plexiglass base was held parallel to the force measuring device along a horizontal plane (Fig. 6). The model was slowly pulled away from the force gauge, thus recording the amount of ĀlastiK tension on the cuspid band. The height of the force was judged to be when the movable arm would just break contact with the stationary table that provided the stop. This was a visual judgement recorded by one observer. The procedure was done once for each test model at each measurement time.

Following initial force measurements, the ten models containing the test chains were placed in a preheated Napco (model 210) water bath maintained at 37^{o} C. The specimens were kept submerged in the water and were only removed for force measurements. The test models were taken from the bath one at a time directly to the measuring device. A rubber bulb air syringe was used to blow water droplets from the contact area of the arm so that the observer could see when contact was broken. After all of the units were measured (mean time = 11 minutes), they were returned collectively to the water bath which decreased in temperature to no less than 35^{o} C. The temperature returned to 37^{o} C. in about 1 hour.

Three tests were run with 60 sections of C1 chain using the method described (one of the runs was done without the .019 x .025 arch wires). Force measurements were recorded at initial placement (0 hour), 30 minutes, 1 hour, and 2 hours. A fourth test run was done with 20 samples stretched buccal and lingual with the arch wires in place as shown in Figures 3, 4, and 5. Force readings were taken at 0 hour, 2 hours, 6 hours, 24 hours, 1 week, 2 weeks, 3 weeks, and 4 weeks. A fifth test run of 10 chains placed only on the lingual buttons of the 10 test models was done. The force decay was recorded during 1 week.

There was slight variation in the distance that the ĀlastiK modules were stretched. The same sized bands were used for each model, but there is variation in the exact width, bracket placement, and button position of the band. This was minimized by careful selection. In order to quantify the distance that the chains were elongated across the simulated 7 mm extraction site, measurements were taken from the distal wing of the second premolar brackets to the distal wing of the cuspid brackets. Button to button measurements were also taken on these bands. This bracket wing distance for the ten test models ranged from 16.6 mm to 17.2 mm with a mean distance of 16.9 mm. The space from premolar button to cuspid button ranged from 16.0 mm to 16.5 mm with a mean distance of 16.3 mm. The entire stretch of the chains from second molar hook to the distal wing of the cuspid bracket ranged from 34.3 mm to 35.5 mm with a mean distance of 34.7 mm. The distance from second molar button to cuspid button ranged from 32.7 mm to 33.6 mm with a mean of 33.1 mm.

A two-factor analysis of variance was used to determine if there was a difference between the test models that would affect the force values of the chains. Force data taken after 2 hours of elongation was selected from three of the test runs. Test conditions at 2 hours were considered to be the same for runs 1, 2, and 4. Buccal and lingual C1 chains, with an arch wire in place, were tested in each of these runs. The test chains were removed from the water bath for force measurements at 30 minutes, 1 hour, and 2 hours during runs 1 and 2. In contrast, the chains in run 4 were removed from the bath for the first time at 2 hours. For this reason, it was desirable to examine a second variable and determine if there was a difference between the force values of the chains at 2 hours for the three test runs (Table 1).

All of the force measurements recorded in the study (Appendix A) were converted from grams to pounds. The mean, variance, standard deviation, and standard error of the mean was calculated for each test run at each measurement time (Appendix B). Using the means of the four week run and taking the log transform of each measurement time, the regression parameter was derived. The log transforms of time were used to place force decay over hours, days, and weeks in an exponential perspective. The predicted force value ($\tilde{Y}$) at each time interval was determined from the regression parameter (Appendix C). A regression curve of the force decay of C1 chains over four weeks was plotted from the parameter values on semi-log graph paper (Fig. 7).

In order to determine the relative amount of error due to the ability of the investigator to accurately record the tension on the cuspid band, the force measurement at 4 weeks was taken twice by the same observer. Two readings were recorded in succession for each test model before the next model was removed from the water bath. The temperature of the bath was 37° C. when the first pair of chains was measured and 13 minutes later when the tenth sample was measured, the water was 36° C. The standard error of the measure ($\sqrt{\frac{\Sigma d^2}{2N}}$) was calculated for the difference (d) between the first and second force readings for each of the 10 test models (N). Differences between each pair of C1 chains at each time interval recorded will have to be greater than the measurement error in order to be considered "real" differences. The measurement error in this study was 28.2 gm (0.062 lb) or 3.8%.

RESULTS

The first, second, and fourth test runs were done with a buccal arch wire in place. The third test run was done without the buccal arch wire and the fifth test run was done without the buccal arch wire and with the force placed on the lingual attachments.

The first, second, and fourth test runs show an initial mean force of nearly 3 pounds for buccal and lingual C1 chains stretched across a simulated 7 mm extraction site. Runs 1 and 2 show that the chains lose close to a pound of force after 30 minutes of elongation. The mean force 2 hours after initial stretch was 1.88 (SD $\pm$0.11) lb, 1.93 (SD $\pm$0.11) lb, and 1.91 (SD $\pm$0.16) lb for test runs 1, 2, and 4, respectively. In run 4, the average force after 4 weeks was 1.65 (SD $\pm$0.16) lb. The rate of mean force decay for the C1 chains in run 4 was 36% in 2 hours, 39% in 24 hours, and 44% after 4 weeks. Combining the data for test runs 1, 2, and 4, the mean force decay after 2 hours was 35% and run 4 decreased another 8% over 4 weeks. The average force at 4 weeks was 14% less than the 2 hour mean force.

Two-factor analysis of variance of the 2 hour mean force values for runs 1, 2, and 4 vs. the mean force values of the chains on each test model for runs 1, 2, and 4 (at 2 hours) did not show a statistically significant difference between the force data (Table 1). The analysis of variance yielded an F ratio of 0.471 for the three test runs (F = 6.01 significant at the 99% confidence level) and an F ratio of 1.490 for the ten test models used in each test run (F = 3.60 significant at the 99% confidence level). It was concluded that there is no significant difference between forces produced on the ten models and no significant difference between force production of the test chains for these three runs since the computed F ratios were not greater than the null hypothesis at the 99% confidence level.

A regression curve based on the relationship of the force of the buccal and lingual C1 chains in run 4 vs. log times was plotted (Fig. 7). The correlation coefficient (Pearson r) of the log transforms of the observed time to the observed force from 2 hours to 4 weeks is -.98; yielding a coefficient of determination of 96%. The standard error of estimate for predicting force values from elongation times of 2 hours to 4 weeks is 0.022 lb. The predicted force from the regression parameter for the batch of C1 chains is 1.92 ($\pm$0.02) lb at 2 hours and 1.68 ($\pm$0.02) lb at 4 weeks.

The arch wires used in test runs 1, 2, and 4 were held to the distal wing of the cuspid bands by the most mesial ring of the buccal C1 chains. In measuring the $\bar{\text{A}}$lastiK tension on the cuspid band, a portion of the recorded force value is the friction of the arch wire pressed against the bracket wing by the stretch of the chain. In order to determine the relative effect of this friction on force measurements, the third 2 hour test run was done without arch wires. The initial mean force of run 3 was 2.61 lb compared to 2.85 lb and 2.80 lb for runs 1 and 2. After 2 hours, the mean force of run 3 was 1.80 lb compared to 1.88 lb and 1.93 lb for runs 1 and 2. The initial mean force of run 3 was about 0.2 lb less than runs 1 and 2 and the average force after 2 hours for run 3 was about 0.1 lb less.

With the first test run, it was found that the mean force of the chains decreased 0.82 lb in 30 minutes, 0.94 lb in 1 hour, and 0.97 lb after 2 hours. When the test C1 chains were removed from the water bath and bench cooled for 10 minutes, the mean force increased 0.14 lb. After bench cooling 20 minutes, the mean force increased 0.32 lb. The chains were then returned to the 37° C. water bath for 30 minutes and the mean force decreased 0.21 lb. It appears that the polyurethane modules "warm up" and undergo changes when taken from room temperatuare to 37° C. water. As the plastic chains are allowed to cool and dry the tension of the modules increases. This is in agreement with Bishara and Andreasen[5] who reported similar findings with K modules. It would seem that the increased temperature of the simulated oral environment contributes to the higher rate of force decay seen in the first 2 hours of elongation.

The fifth test run was done with a single C1 chain stretched only on the lingual buttons of the test models. The purpose of this run was to obtain comparative force values of a single chain elongated across the simulated 7 mm extraction site without being stretched over brackets or an arch wire. The initial mean force was 1.16 (SD $\pm$0.12) lb for the ten single chains. This average force value decreased to 0.70 (SD $\pm$0.10) lb in 2 hours and was 0.63 (SD $\pm$0.11) lb after 1 week. The rate of mean force decay was 40% in 2 hours, 43% in 24 hours, and 46% after 1 week. The average force decreased by 10% from 2 hours to 1 week. This force decay from 2 hours to 1 week represented 6% of the total decay from 0 hour to 1 week.

DISCUSSION

One of the purposes of this study is to determine the rate of force decay for buccal and lingual C1 chains stretched from posterior bands to a cuspid band at selected time intervals up to 4 weeks. For this investigation, the rate of the average force decay was 14% from 2 hours to 4 weeks which represented 8% of the total mean force decay over the 4 weeks. The mean force of the chains (under test conditions determined by ANOVA to be statistically the same) was highly correlated to the log transforms of the time intervals of measurement from 2 hours to 4 weeks; a Pearson r of -.98. The log of each measurement time places the time intervals in an exponential relationship for comparing hours with weeks.

Squaring the Pearson r yields a coefficient of determination of .96. Thus, 96% of the variance is accounted for and 4% of the variance is due to factors other than time. With this high linear relationship established, regression analysis of the data was plotted on semi-log graph paper to predict the force of the chains from time of elongation. The slope of the plotted regression line indicates the rate of force decay for the C1 chains from 2 hours to 4 weeks. The standard error of slope of the line for the data is .01 lb.

The elongation distances from second premolar to cuspid band for both the buccal and lingual C1 chains in this study was close to 17 mm for each chain tested. Similarly, a 17 mm stretch distance was determined by Wong[8] to be representative of the average interbracket distance between the cuspid and second premolar for his study of C2 chains. This distance, although based on an average 7 mm first premolar, is probably at the high side of the range of elongation for chains stretched clinically from second premolar to cuspid band during cuspid retraction. It was this observer's impression that the test chains were stretched as far as he has experienced clinically and further than the average elongation required during cuspid retraction. By the time the case is banded and larger arch wires are placed, the extraction space appears to be reduced. This may not be the case with bonding and placement of chains with initial arch wires.

Previous studies[4,5,10] of ĀlastiK chains and modules have demonstrated that with increases in elongation, mean force values increase. However, in contrast to the amount of force produced, Varner and Buck[10] demonstrated with KX-2 ĀlastiKs that increases in elongation did not change the rate of mean force decay. Therefore, it would be expected that C1 chains, attached to a cuspid less than 7 mm from the second premolar, would show force values less than those of the present study, but similar force decay rates. The force decay from 2 hours to 4 weeks would probably be the same if samples from the same batch of chains used in this study were placed on the same test models with only the elongation distance reduced a fixed amount. If the stretch distance were reduced while the same chains were in place (as in tooth movement), then the rate of force decay would be expected to decrease as shown by Hershey and Reynolds[7]. Their study of 540 samples of four different manufactured chains showed a mean force decay from 24 hours to 6 weeks of 5% at a fixed distance. When the stretch distance was decreased at the rate of 0.25 mm per week (simulated tooth movement), the mean force of the chains decreased by a rate of 15% from 24 hours to 4 weeks and 19% from 24 hours to 6 weeks. The mean force of the C1 chains in this study decreased by a rate of 6% of the initial mean force from 24 hours to 4 weeks at a fixed stretch distance.

The other purpose of this study is to quantify the force produced by C1 chain $\bar{A}$lastiKs when used for cuspid retraction across an "average" extraction site. The buccal and lingual C1 chains in test run 4 (with an arch wire) showed an observed mean force of 2.97 lb (1346 gm) initially. At 2 hours, the mean force decreased to 1.91 lb (868 gm) and it was 1.82 lb (826 gm) after 24 hours. The observed mean force after 4 weeks was 1.65 lb (748 gm).

The predicted force derived from the regression parameter of the observed force of the buccal and lingual chains is 1.92 lb at 2 hours, 1.82 lb at 24 hours, and 1.69 lb at 4 weeks. This is at an elongation where the buccal chain is stretched over an arch wire. The standard error of estimate of the data is 0.02 lb. The standard error of estimate is the standard deviation of the errors of predicting $\tilde{Y}$ from X and it puts the predictions in a confidence interval band when predicting from the regression line.

When a single C1 chain was placed only on the lingual buttons of the test models (test run 5) and stretched across the simulated extraction site, the observed initial mean force was 1.16 lb (526 gm). At 2 hours, the average force decreased to 0.70 lb (317 gm) and it was 0.66 lb (298 gm) after 24 hours. This test run was followed for 1 week without buccal arch wires in place and the mean force after 1 week was 0.63 lb (287 gm).

The use of an arch wire in test runs 1, 2, and 4 adds additional elongation distance to the buccal C1 chain. As stated, it has been demonstrated[4,5,10] that ĀlastiK force increases as the material is stretched longer distances. Also, each ring of the four-unit chain is stretched around the bracket wings which adds to the overall elongation of the buccal chain compared to the lingual chain. This could contribute to the high force values produced by the buccal-lingual chain combination. It would be expected that the addition of a buccal chain to the lingual chain across the simulated 7 mm extraction site would double the force[12]. The mean "stretch" distance is nearly the same, differing by 0.6 mm (16.9 mm on the buccal compared to 16.3 mm on the lingual). Twice the 2 hour mean force of the lingual chain (run 5) would be 1.4 lb. The 2 hour mean force of buccal and lingual chains, without arch wires was 1.8 lb (run 3) and 1.9 lb with arch wires (runs 1, 2, and 4); one half pound greater.

The buccal chain is not only stretched more than the lingual chain when circling brackets, it is further elongated as it is placed over the bracket wings. A hemostat was used to grasp the chain and stretch each link over the corresponding brackets as is done clinically. Each ring and connecting filament of the C1 chain was in essence "prestretched". Young and Sandrik[12] found a statistically significant increase in force when prestretching ĀlastiK grey CK chains and comparing them with a CK control over a 24 hour time period. They could not show the same effect with prestretched grey C2 chains. They did show that prestretching the

CK chains also affected the rate of force decay over 24 hours. With increased distance of prestretching, the average force decay decreased when compared to the CK control.

In the present study, the rate of mean force decay for the single lingual grey C1 chain was 40% from 0 hour to 2 hours and 43% at 24 hours. The buccal and lingual chains without an arch wire had a mean force decay of 31% in 2 hours. Runs 1, 2, and 4 (with an arch wire and double chains) had a 2 hour force decay of 34%, 31%, and 36%, respectively. The rate of mean force decay in the fourth test run was 39% after 24 hours and 41% in 1 week compared to 46% for the single lingual chain at 1 week. Interestingly, when viewed from 2 hours to 1 week (when all test chains are handled on the test models in the same way) the mean force decay is nearly the same; differing by 1%.

The use of simulated clinical quadrants of bands, brackets, and arch wires in which polyurethane modules are manipulated in a manner similar to their clinical usage may provide a more accurate picture of their behavior during orthodontic treatment especially in view of the high forces produced by the test chains in this study. The force production was higher than reported by Varner and Buck[10] with KX-2 $\bar{A}$lastiKs elongated on an Instron testing instrument. In addition, the rate of mean force decay over 24 hours for the test C1 chains was considerably lower than reported by Andreasen and Bishara[4] in which the C1 chains were stretched through space on wire frames. The forces in the present investigation (including the single lingual chain) were a great deal higher and the overall decay rate much lower than recorded by Wong[8] when he stretched double-ring sections of C2 chain on brackets welded to stainless steel plates a similar 17 mm distance.

Varner[15] found a statistical difference in the initial mean force between three different batches of KX-2 ĀlastiKs. Variation in the quality of ĀlastiK material should be considered when making comparisons between different studies. ĀlastiKs are surely subject to difficulties in quality control during manufacture as is any product. The quality of the raw materials used in producing ĀlastiKs may vary over the years. Polyurethanes in general have been refined within recent years due to increased biomedical applications[16]. The length of time and the manner of storage between the processing of ĀlastiKs and their testing will likely vary. The material used in the present study was very fresh and had been processed the week prior to delivery according to the manufacturer*. The first test run was done within two weeks of processing and the test chains were kept in a paper envelope at room temperature until their use (with no exposure to sunlight).

A portion of the results of this study is certainly experimental error. The force gauge was calibrated before and after testing, and the clutch to hold the highest force reading worked well. The chains on the test models were taken directly from the water bath to the gauge for force measurements and were not removed from the brackets. The chains were elongated just slightly to record the force. The movable arm appeared to slide freely on the wet, polished plexiglass surface. The only apparent difficulty came when the observer had to judge the breaking of contact between the movable arm and the stationary plexiglass stop. This judgment was much more difficult when the models were wet as opposed to the dry initial force measurements. A rubber bulb air syringe was used to clear water droplets from the contact area, but at times small amounts

---

* ĀlastiKs are manufactured by Mod Com, Incorporated of Canby, Oregon.

of moisture would obscure the contact of the plexiglass arm with the plexiglass stop. As a result, the movable arm was opened varying degrees and the chains were stretched slightly different amounts during force measurements. A short blast of compressed air could have been used to clear the water. It was thought at the time that this volume of air may cool and dry the test chains thus affecting their tension.

In order to place this judgment by the observer into quantitative terms, the force of the C1 chains was recorded twice in succession at 4 weeks. The second force measurement taken immediately after the 4 week measure had a difference ranging from +30 gm to -70 gm with a standard error of the measure of $\pm$28 gm. During test runs 1 and 2, the force recorded for individual pairs of chains increased as much as 100 gm while the mean force at that time interval was decreasing compared to the previous time measurement. Even if the recorded force values were in error as much as 100 gm (0.2 lb), the standard error of the measure for the test runs would be 70.7 gm or 0.16 lb. This would still place the force of the buccal and lingual chains elongated across the simulated 7 mm extraction site in a comparable force range to Varner and Buck's[10] highest (40 mm) elongation of KX-2 Ālastiks. This suggests that space closure could possibly be accomplished along the arch wire with buccal and lingual C1 chain Ālastiks that are capable of similar high force production.

As mentioned earlier, the friction involved in the force measurement process should increase the force values recorded. The friction of the movable arm along the plexiglass base was so slight that when chains were not attached, the sliding of the arm would not register a force on the gauge. With chains attached, the movable arm only had to move a fraction to break contact with the plexiglass stop while sliding along the base. The friction of the mesial ring of the buccal chain holding the arch wire against the cuspid bracket wing likely increases force values recorded by the gauge since the wire and the chain have to slide when ĀlastiK tension is measured. The initial force of run 3 (no arch wires) was 0.2 lb less than runs 1 and 2 with arch wires. After 2 hours, the no arch wire run had a recorded force value 0.1 lb less than all three arch wire runs at 2 hours. The standard error of the measure of 0.06 lb (28 gm) tends to indicate that there is a difference when the arch wire is not present while taking force measurements. The question then arises is all of this measurement difference due to friction? The buccal chain is stretched further when the arch wire is in place and this should result in increased force values recorded. Overall, force values of 0.2 lb and 0.1 lb are very small when looking at forces in the 2 lb to 3 lb range. This leads to the impression that friction inherent in the test model system contributed very slightly to the high force values recorded.

Forces of 2.97 lb decreasing to 1.65 lb over four weeks for the buccal-lingual C1 chain combination may concern some[17,18,19] as excessive. In initiating a tooth movement response, small force is all that is necessary[20] and it may be desirable[21,22]. ĀlastiK chains offer the option of placing a ring between brackets thus reducing the tension on the connecting filaments of the chain and therefore reducing the force. A single buccal chain can be placed to reduce the force. The presence of both buccal and lingual attachments on a tooth provides additional options. Klein[23] has used a single lingual C1 chain to initiate cuspid retraction; primarily in cases where the cuspids are rotated to the distolingual. Klein[23] maintains that the force of the single lingual chain will rotate as well as retract a cuspid and will aid in bringing the distal wing of a twin bracket to the arch wire. The initial mean force of the single lingual chains stretched across the simulated 7 mm extraction site was 1.16 lb (526 gm) which decreased to 0.70 lb (317 gm) in 2 hours and to 0.66 lb (298 gm) after 24 hours. Klein[23,24] will usually follow the single lingual chain with both buccal and lingual chains until anterior spacing appears. Once cuspid retraction has been initiated, the use of "high" forces may not hamper tooth movement as has been suggested[19]. Hixon and co-workers[25,26] proposed that forces up to 1,000 gm (2.2 lb) may hasten retraction of cuspids although this observation was based on a very small sample size. Boester and Johnston[27] could not show that tooth movement is more rapid with increasing force, but their investigation of cuspid retraction did suggest that space closure proceeds equally at about 0.5 mm per week with forces ranging from 5 to 11 ounces (140 to 310 gm).

Young and Sandrik[12] followed $\bar{A}$lastiK chains for 24 hours and then used semi-log regression analysis to predict the behavior of the chains at 4 weeks. In the present study, the $\bar{A}$lastiK C1 chains were followed over 4 weeks and semi-log regression analysis was used to plot the predicted force vs. time. Although it is this observer's understanding that predicting beyond the measured time intervals is not valid, it is nevertheless interesting to extend the regression line out to 8 weeks. The predicted force for the buccal and lingual C1 chains at 8 weeks would be 1.66 ($\pm$0.02)lb. Perhaps, $\bar{A}$lastiK C1 chains do not need to be changed every 3 to 4 weeks because of inherent force decay. If one of the advantages of polyurethane modules is continuous force, then maybe the tooth movement process should not be disturbed at regular predetermined intervals. Perhaps, the interbracket distance could be measured at 3 to 4 week intervals and the modules replaced with changes in tooth position.

This speculation may not be within the scope of this study. However, ten years ago the force ranges, decay rates, and effectiveness of $\bar{A}$lastiKs were unknown to the profession; they were only speculation. Since that time, the literature reviewed in this paper shows $\bar{A}$lastiK forces unquestionably capable of tooth movement; low force decay rates when viewed from 2 hours to 4 weeks rather than 0 hour to 4 weeks; and that plastic modules can be clinically effective.

The questioning of the validity of other studies that did not use conditions more closely simulating a clinical situation does not enhance the validity of the present study. It only attempts the better understanding of the behavior of materials and techniques that are used clinically because they get the job done. This thought is summed up by E. H. Hixon[25] when he wrote: ". . . the advancement of clinical orthodontics depends not only on improved mechanics but also on constant re-examination of our biologic theories in the unending quest for better working (clinical) hypotheses. This is one of the responsibilities that distinguish a professional person from a technician . . ."

SUMMARY AND CONCLUSIONS

ĀlastiK Medium Grey C1 chains that had been cut into sections of 4 rings were tested two at a time on ten plexiglass models containing bands, brackets, and arch wires simulating a clinical situation.

A test section of C1 chain was stretched from second molar hook to molar bracket to premolar bracket and then across a simulated 7 mm extraction site to the distal wing of a cuspid bracket.

A second chain was stretched on the lingual from second molar lingual button to molar lingual button to premolar button and then across the 7 mm extraction site to a cuspid button.

A gauge measured the force on the cuspid band from the buccal and lingual ĀlastiK chains in an effort to quantify the force on a cuspid retracted across a 7 mm extraction site.

A total of 90 sections of four-ring C1 chains were tested in 37° C. water for three different time periods in five separate test runs.

Ten pairs of chains were tested at a constant stretch over a 4 week period at a fixed distance with no attempt to simulate tooth movement by reducing the distance during the test period.

The buccal C1 chain was stretched over a .019 x .025 arch wire with each ring circling the bracket to hold the arch wire in place as in a clinical situation.

Thirty pairs of C1 chains had an initial mean force of 2.9 lb; after 2 hours, the mean force decreased to 1.9 lb.

The mean force for ten pairs of buccal and lingual C1 chains was 1.8 lb after 24 hours and 1.7 lb at 4 weeks.

The rate of mean force decay was 36% after 2 hours of elongation, 39% at 24 hours, and 44% in 4 weeks (an additional 8% after 2 hours).

The average force decay for ten pairs of C1 chains tested was 14% when viewed from 2 hours to 4 weeks.

The mean force of the chains at each measurement time showed a high correlation (r = -.98) to the log transforms of the time intervals of measurement over 4 weeks.

A regression curve based on the relationship of the force of the buccal and lingual C1 chains vs. log times was plotted on semi-log graph paper.

The buccal-lingual C1 chain combination produced forces similar to those reported for KX $\bar{A}$lastiKs[10,15].

The high force production and low force decay of the $\bar{A}$lastiK C1 chains in this study indicate forces subsequent to 2 hours are capable of tooth movement, including cuspid retraction.

Test conditions closely simulating the clinical manner in which plastic modules are used may be of significance when quantifying force production and force decay rate.

Whatever the quality of the $\bar{A}$lastiK chains tested may have been and regardless of how they had been handled, the reported force decay, this study included, has consistently been between 5% and 15% from 24 hours to 3 or 4 weeks[4,7,8,11] (reported force decay between initial activation and 24 hours has ranged from 35% to 75%).

Therefore, the changing of ĀlastiK chains prior to 3 or 4 weeks of service would not likely increase their clinical force production unless thay were replaced daily (at which point the clinician looses the uninterrupted force advantage of ĀlastiKs and may just as well have the patient use elastics).

BIBLIOGRAPHY

1. Tweed, C. H. "A Philosophy of Orthodontic Treatment," American Journal of Orthodontics and Oral Surgery, 31:74-103, 1945.

2. Anderson, R. M. "A Return to Large Nonresilient Straight Arch Wires," American Journal of Orthodontics, 66:9-39, 1974.

3. Unitek Corporation "ĀlastiK Orthodontic Force Modules," Unitek Corporation Manufacturer's Bulletin, Monrovia, California, 1972.

4. Andreasen, G. F. and Bishara, S. E. "Comparison of ĀlastiK Chains with Elastics Involved with Intra-Arch Molar to Molar Forces," Angle Orthodontist, 40:151-158, 1970.

5. Bishara, S. E. and Andreasen, G. F. "A Comparison of Time Related Forces Between Plastic ĀlastiKs and Latex Elastics," Angle Orthodontist, 40:319-328, 1970.

6. Ware, A. L. "Some Properties of Plastic Modules Used for Tooth Movement," Australian Orthodontic Journal, 2:200-202, 1971.

7. Hershey, H. G. and Reynolds, W. G. "The Plastic Module as an Orthodontic Tooth-Moving Mechanism," American Journal of Orthodontics, 67:554-562, 1975.

8. Wong, A. K. "Orthodontic Elastic Materials," Angle Orthodontist, 46:196-205, 1976.

9. Kovatch, J. S., Lautenschlager, E. P., Apfel, D. A., and Keller, J. C. "Load-Extension-Time Behavior of Orthodontic ĀlastiKs," Journal of Dental Research, 55:783-786, 1976.

10. Varner, R. E. and Buck, D. L. "Force Production and Decay Rate in ĀlastiK Modules," Journal of Biomedical Materials Research, 12:361-366, 1978.

11. Ash, J. L. and Nikolai, R. J. "Relaxation of Orthodontic Elastomeric Chains and Modules in Vitro and in Vivo," Journal of Dental Research, 57:685-690, 1978.

12. Young J. and Sandrik, J. L. "The Influence of Preloading on Stress Relaxation of Orthodontic Elastic Polymers," Angle Orthodontist, 49:104-109, 1979.

13. Brummond, G. Personal communication. Mod Com, Inc., 1979.

14. Horowitz, S. L. and Hixon, E. H. The Nature of Orthodontic Diagnosis, St. Louis, 1966, The C. V. Mosby Company, p. 156.

15. Varner, R. E. "Force Production and Decay Rate in ĀlastiK Modules," Certificate Thesis, University of Oregon Health Sciences Center, 1974.

16. Wilkes, G. L., Dziemianowicz, T. S., Ophir, Z. H., Artz, E., and Wildnauer, R. "Thermally Induced Time Dependence of Mechanical Properties in Biomedical Grade Polyurethanes," Journal of Biomedical Materials Research, 13:189-206, 1979.

17. Storey, E. E. and Smith, R. "Force in Orthodontics and Its Relation to Tooth Movement," Australian Journal of Dentistry, 56:11-18, 1952.

18. Begg, P. R. "Differential Force in Orthodontic Treatment," American Journal of Orthodontics, 42:481-510, 1956.

19. Begg, P. R. Begg Orthodontic Theory and Technique, Philadelphia, 1977, W. B. Saunders Company, p. 142.

20. Buck, D. L. and Church, D. H. "A Histologic Study of Human Tooth Movement," American Journal of Orthodontics, 62:507-516, 1972.

21. Reitan, K. "Some Factors Determining the Evaluation of Forces in Orthodontics," American Journal of Orthodontics, 43:32-45, 1957.

22. Reitan, K. "Tissue Behavior During Orthodontic Tooth Movement," American Journal of Orthodontics, 46:881-900, 1960.

23. Klein, P. Personal Communication, 1979.

24. Hixon, E. and Klein, P. "Simplified Mechanics: A Means of Treatment Based on Available Scientific Information," American Journal of Orthodontics, 62:113-141, 1972.

25. Hixon, E. H., Atikian, H., Callow, G. E., McDonald, H. W., and Tacy, R. J. "Optimal Force, Differential Force, and Anchorage," American Journal of Orthodontics, 55:437-457, 1969.

26. Hixon, E. H., Aasen, T. O., Arango, J., Clark, R. A., Klosterman, R., Miller, S. S., and Odom, W. M. "On Force and Tooth Movement", American Journal of Orthodontics, 57:476-489, 1970.

27. Boester, C. H. and Johnston, L. E. "A Clinical Investigation of the Concepts of Differential and Optimal Force in Canine Retraction," Angle Orthodontist, 44:113-119, 1974.

Table I: Two-factor analysis of variance of the force of buccal and lingual C1 chains, elongated on ten separate test models (Variable A), after 2 hours of elongation with an arch wire and recorded for three separate test runs (Variable B).

ANOVA Design	Means of Variable A	Variances of Variable A	Means of Variable B	Variances of Variable B
b_1 b_2 b_3				
a_1	1.962	0.018	1.880	0.012
a_2	1.932	0.005	1.931	0.012
a_3	1.778	0.003	1.913	0.025
a_4	1.837	0.024		
a_5	1.822	0.024		
a_6	1.940	0.025		
a_7	1.947	0.008		
a_8	1.851	0.024		
a_9	1.955	0.0002		
a_{10}	2.057	0.002		

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F Ratios
A	0.18934363	9	0.02103818	1.490256
B	0.01329846	2	0.00664923	0.471003
AB	0.25410886	18	0.01411715	1.000000

For the test model variable, F = 3.60 significant at the 99% confidence level.

For the test run variable, F = 6.01 significant at the 99% confidence level.

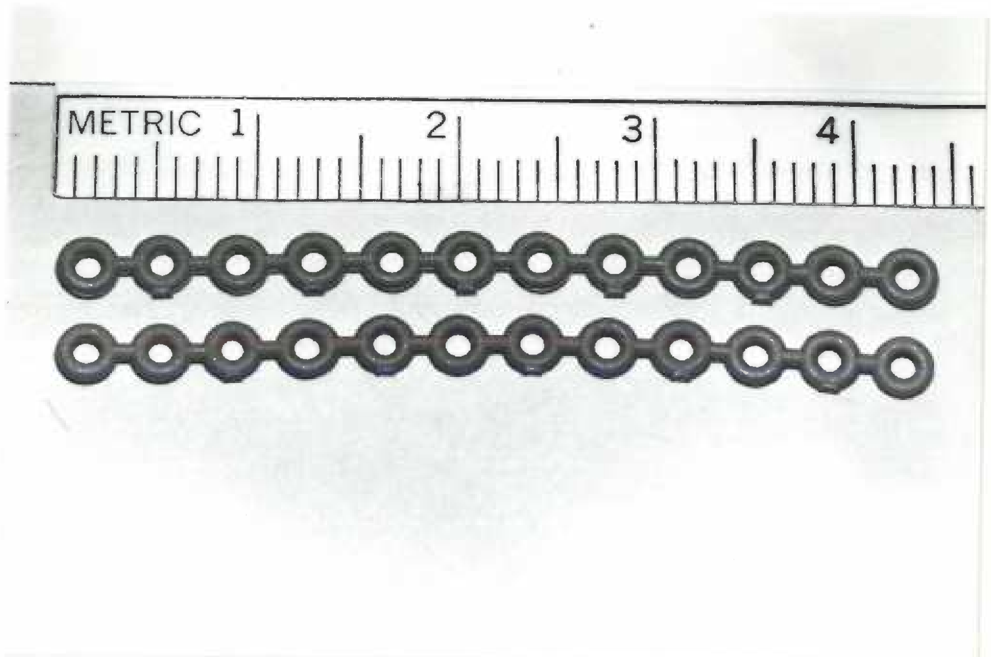

Fig. 1: ĀlastiK C1 chains.

Fig. 2: Test models for C1 chains.

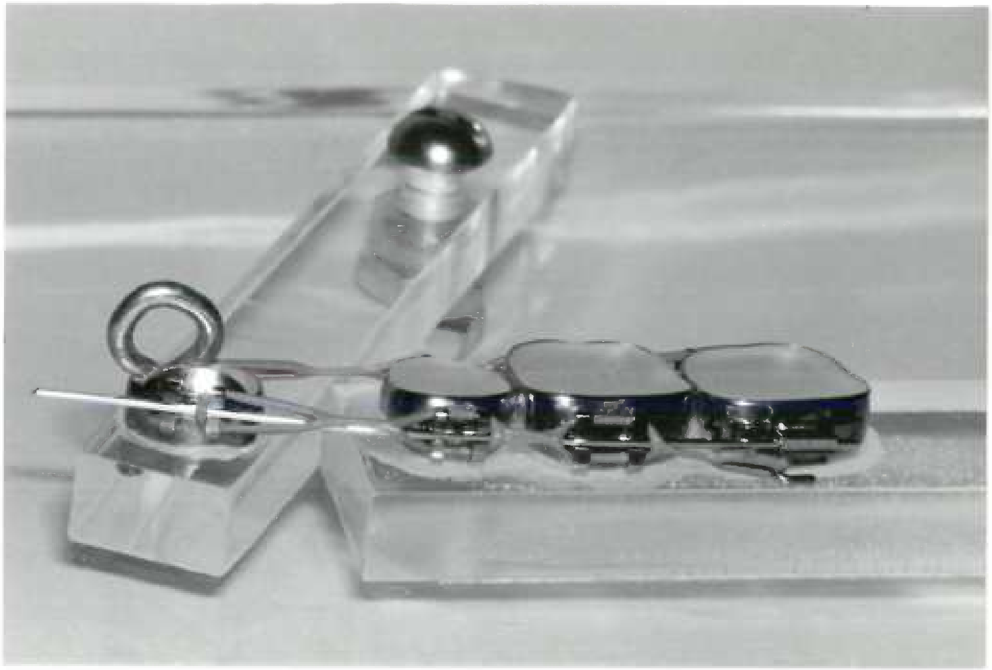

Fig. 3: Buccal view of C1 chain in place on a test model.

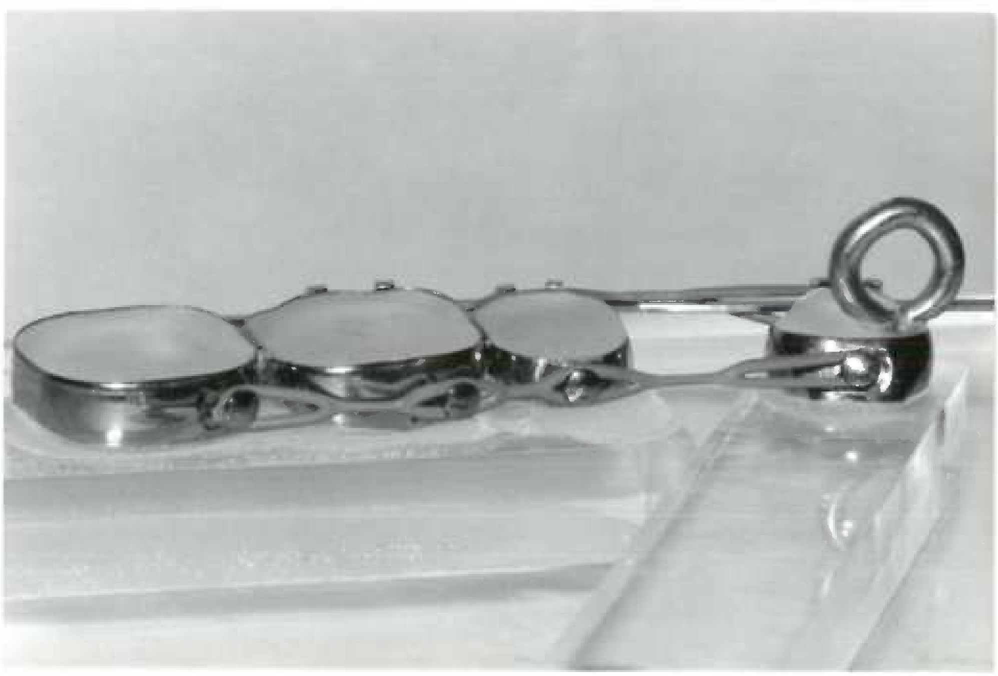

Fig. 4: Lingual view of C1 chain in place on a test model.

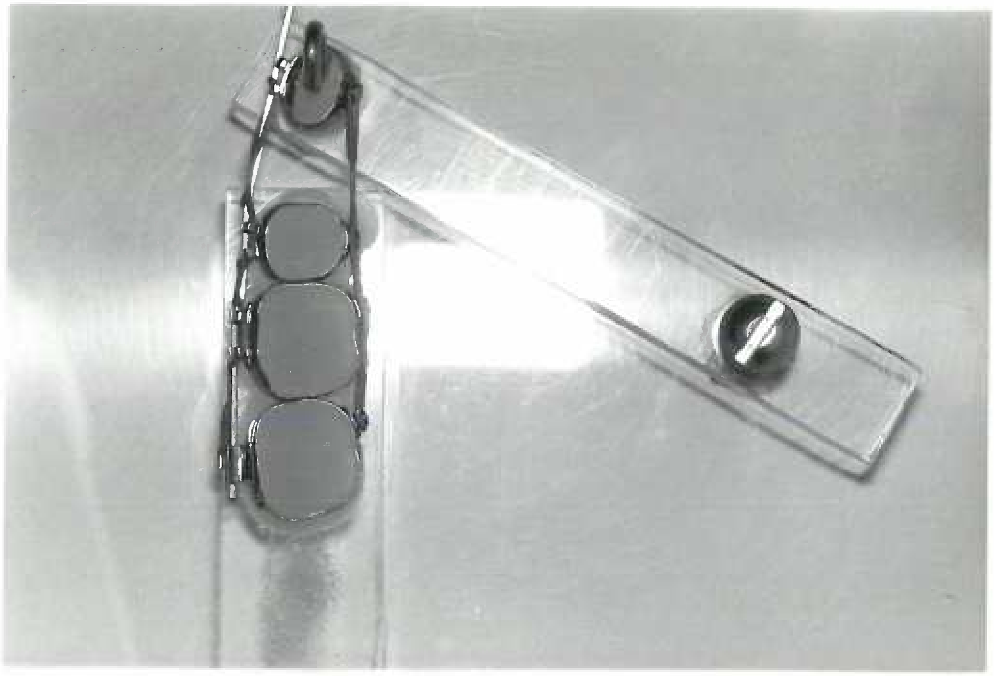

Fig. 5: Occlusal view of C1 chains on a test model with the arch wire in place.

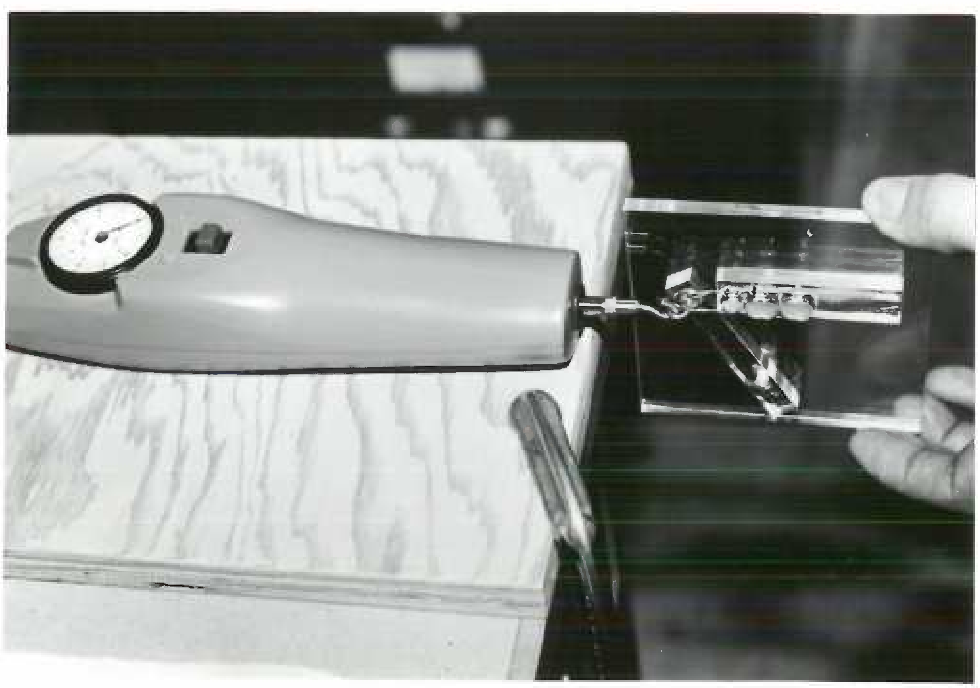

Fig. 6: Placement of a test model horizontal to the force gauge as tension on the cuspid band is recorded.

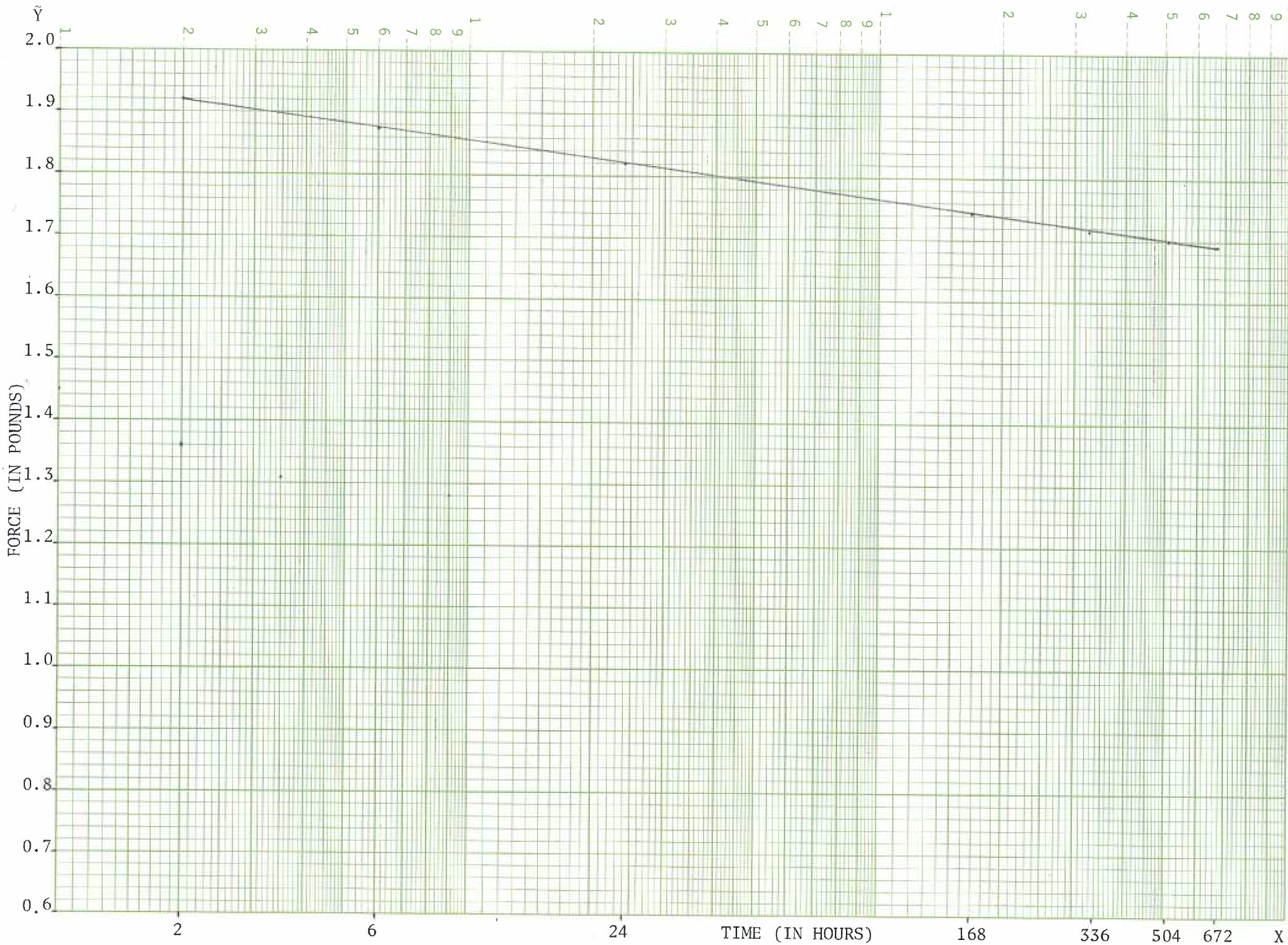

Fig. 7: Regression curve of force vs. time of C1 chains.

Appendix A: Experimental Data of Force (in grams) Vs. Time.

	0	0.5 hr	1 hr	2 hr	10 minute bench cool	20 minute bench cool	30 minutes in bath
First Run	1330	850	800	820	900	980	820
	1400	1060	1100	870	1010	1190	1020
	1260	840	700	830	820	850	810
	1220	960	880	900	1000	1130	930
	1220	910	930	900	980	1070	970
	1240	920	840	800	790	990	900
	1250	900	820	850	900	900	870
	1250	830	720	760	830	880	800
	1370	980	950	890	980	1010	960
	1400	950	940	910	950	1000	980
Second Run	1350	960	980	930			
	1400	930	880	910			
	1220	910	840	780			
	1280	900	870	840			
	1320	960	920	820			
	1190	980	960	900			
	1180	950	860	870			
	1170	880	870	890			
	1400	1010	940	880			
	1200	950	980	940			
Third Run	1310	1000	990	940			
	1160	910	920	830			
(No Arch Wire)	1120	870	820	790			
	1150	840	840	780			
	1180	890	860	850			
	1200	760	740	720			
	1140	820	800	820			
	1140	890	800	760			
	1250	910	940	900			
	1190	920	820	770			

Appendix A (continued): Experimental Data of Force (in grams) Vs. Time.

	0	2 hr	6 hr	24 hr	1 wk	2 wk	3 wk	4 wk	Second measure
Fourth Run	1400	920	910	890	880	890	910	840	870
	1400	850	870	840	790	810	800	800	830
	1300	810	810	830	860	860	730	720	700
	1290	760	790	720	760	770	750	710	690
	1330	760	770	710	730	710	660	670	710
	1360	940	850	840	850	760	740	670	670
	1390	930	950	920	850	860	850	850	810
	1340	870	840	790	720	710	750	650	710
	1380	890	830	860	810	770	720	770	700
	1270	950	890	860	740	750	780	800	760
Fifth Run	570	330		350	340				380
	640	360		310	240				260
(One Chain On	580	390		350	370				380
Lingual Only)	500	290		270	300				310
	520	370		300	260				240
	450	260		270	240				220
	480	290		290	260				220
	500	310		260	270				230
	490	290		290	240				200
	530	280		290	350				350

Appendix B: Means, Variances, Standard Deviations, and Standard Error of the Means of the Experimental Data (in pounds).

	0	0.5 hr	1 hr	2 hr	10 minute bench cool	20 minute bench cool	30 minutes in bath
First Run							
$\bar{X}$	2.852	2.028	1.913	1.880	2.019	2.204	1.997
S^2	0.026	0.025	0.069	0.012	0.031	0.057	0.030
SD	0.162	0.157	0.262	0.110	0.177	0.239	0.173
SEM	0.051	0.050	0.083	0.035	0.056	0.075	0.055
Second Run							
$\bar{X}$	2.801	2.079	2.006	1.931			
S^2	0.040	0.007	0.013	0.012			
SD	0.201	0.086	0.116	0.111			
SEM	0.063	0.027	0.037	0.035			
Third Run							
$\bar{X}$	2.610	1.942	1.880	1.798			
S^2	0.016	0.020	0.029	0.022			
SD	0.128	0.143	0.167	0.147			
SEM	0.040	0.045	0.053	0.047			

	0	2 hr	6 hr	24 hr	1 wk	2 wk	3 wk	4 wk	Second measure
Fourth Run									
$\bar{X}$	2.967	1.913	1.876	1.820	1.761	1.739	1.695	1.649	1.642
S^2	0.011	0.025	0.015	0.022	0.017	0.020	0.024	0.026	0.023
SD	0.105	0.158	0.122	0.150	0.131	0.140	0.156	0.162	0.151
SEM	0.033	0.050	0.039	0.047	0.041	0.044	0.049	0.051	0.048
Fifth Run									
$\bar{X}$	1.159	0.699		0.657	0.632				0.615
S^2	0.015	0.009		0.005	0.012				0.024
SD	0.124	0.096		0.069	0.109				0.154
SEM	0.039	0.030		0.022	0.035				0.049

Appendix C: Regression Analysis of Force Vs. Time for the Four Week Run of C1 Chains.

Observed Time	2 hr	6 hr	24 hr	168 hr (1 wk)	336 hr (2 wk)	504 hr (3 wk)	672 hr (4 wk)
Log Transform of Observed Time (X)	0.301029	0.778151	1.380211	2.225309	2.526339	2.702430	2.827369
Observed Force In Pounds (Y)	1.913	1.876	1.820	1.761	1.739	1.695	1.649
Predicted Force In Pounds ($\tilde{Y}$)	1.9206	1.8761	1.8200	1.7412	1.7132	1.6968	1.6851

The correlation coefficient of time variable (X) to mean force variable (Y) = -.977696

The equation for the straight line in regression analysis is: $\tilde{Y} = a + bX$

$\tilde{Y}$ = predicted value of Y

a = intercept of the line with the y axis

b = slope of the line

The regression parameter for the data is:

$$\tilde{Y} = -.093212\ X + 1.948657$$

The standard error of intercept of the line = .018299 lb

The standard error of slope of the line = .008954 lb

The standard error of estimate for predicting $\tilde{Y}$ from X = .022012 lb