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Effects of Stress Relief to Decrease Force Loss in Retraction Springs

Richard Earl Dunn

Abstract

EFFECTS OF STRESS RELIEF TO DECREASE FORCE
LOSS IN RETRACTION SPRINGS

By

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Orthodontic wire may be heat treated to relieve residual stresses resulting from the formation of bent configurations. This study utilized electronic equipment to detect and record the initial amount of activation force, and the amount of force lost due to the intrinsic properties of the wire. The information was gathered at three hour intervals over fifteen one-week periods. The data were statistically analyzed by a computer to determine means and standard deviations. A general linear hypothesis was utilized to test covariants and the main effects.

A total of forty-eight wires were tested. Closed helix retraction springs fabricated from .016" X .016" Blue Elgiloy, Permachrome Standard, and Multiphase were tested in non-heat treated and heat treated conditions. Hilgers retraction springs fabricated from .016" X .016" Blue Elgiloy were tested in a non-heat treated state.

Activation force for helical closing loop, retractors, Ricketts retractors, and Hilgers retractors and grey chain were observed.

The data indicated that without heat treatment Blue Elgiloy had greater force loss than Multiphase and Permachrome. However, after heat treatment of the three types of wires, Blue Elgiloy had less force loss than Permachrome and Multiphase. The effects of heat treatment for the three types of wires were statistically significant. Three methods for heat treatment of Blue Elgiloy were tested. Heat treatment of Blue Elgiloy using an oven, resistance or cigarette lighter, revealed no statistical differences.

The wire design of a helical closing loop versus a Hilgers retractor did not significantly decrease the amount of force lost in non-heat treated Blue Elgiloy. However, the wire design did affect the distance for activation. A Ricketts retractor had the greatest distance for activation of 150 grams. Hilgers retractor had intermediate distance, and a helical closing loop had the least distance for activation. Grey chain activated 1 1/2 millimeters exerts a force of 195 grams. The force of activation decreased 66 grams at the end of 24 hours.

LOMA LINDA UNIVERSITY

Graduate School

EFFECTS OF STRESS RELIEF TO DECREASE FORCE LOSS IN RETRACTION SPRINGS

by

Richard Earl Dunn

A Thesis in Partial Fulfillment of the Requirements for the Degree of Master of Science in Orthodontics

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June 1983

Each person whose signature appears below certifies that this thesis in his/her opinion is adequate, in scope and quality, as a thesis for the degree Master of Science.

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INTRODUCTION

Orthodontic forces that are applied for tooth movement are useful only as they initiate desirable biologic changes. Research indicates that orthodontic appliances capable of delivering light continuous forces are highly desirable because of their distribution of that force.[1-2] Various clinicians have observed that the biological response of root resorption and bone remodeling is a result of the distribution of the coronally-applied force.[3-4]

Because orthodontists are concerned about the application of force in retracting teeth separately or en masse, looped archwires are employed routinely by many treatment philosophies. In the formation of loops the wire is taken well beyond its elastic limit, and permanently deformed into the configuration that is desired. However, this bending process leaves the wire with residual stress. Relieving of this residual stress may be accomplished via some method of heat treatment. The purpose of this study was to answer the following questions:

1. What is the amount of force loss in closed helical retraction springs of nonheat treated and heat treated samples?
2. Is stress relief for closed helical retraction springs necessary or advisable?
3. Does the type of wire influence that decision?
4. Does the method of heat treatment for blue elgiloy yield significant differences?

REVIEW OF THE LITERATURE

Throughout the evolution of various treatment modalities orthodontists have been intrigued by the idea of generating forces that will be continuously working on the dentition at optimum force levels between appointments. Burstone's work suggests that a benefit derived from using an orthodontic spring is that sudden changes in force application are eliminated. He points out that the quest for finding the constant force, involves the utilization of springs with low load-deflection rates. If the wire configuration and dimensions remain unchanged, rates can be altered only by using various alloys with different moduli of elasticity.[5] As a comparison of constant force application, Andreasen and Bishara noted that

Alastik chains are effective for consolidating arches that have generalized spacing but were less effective in retracting canines. Based on their research, for intra-arch molar to molar forces, they recommend that the clinician use forces about four times greater than the ideal because after the first 24 hours the force has decayed 75 percent.[6] In another study, Andreasen and Bishara noted that with plastic Alastiks and latex elastics used for Class II and Class III correction, the average decay after 24 hours was less for rubber elastics than for plastic Alastiks, but both require the clinician to consider the amount of decay when making the initial application of force.[7]

Kohl noted that after heat treating stainless steel the elastic qualities of the archwire increased so that it would be able to assume its original shape after distortion. He pointed out that because the wire will have more resistance to permanent set when deflected, a maximum force will be applied during the range of tooth movement.[8]

In recent years, manufacturers have introduced various grades of austenitic stainless steel for orthodontic wires. Basically all orthodontic stainless steel wires are of the 18-8 type. (18 percent chromium and

8 percent nickel) Howe, Greener and Crimmins' research used various grades of stainless steel wire with differing amounts of nickel.They tested the improvement of the elastic properties after heat treatment. Their heat treatment was a type of electric resistance furnace but, it required that the wire samples and the stainless steel jig that was holding them be heated. Because of the mass of the jig, heating the wire resulted in a 5 to 9 minute thermal lag, depending on the heat treatment temperature. Their results showed that the type of stainless steel wire with an increase of nickel and molybdenum, demonstrated higher strength properties of increased modulus of elasticity and greater yield strength, after heat treatment. The largest improvement occurred for temperatures between 700 - 900°F.[9]

The ideal time and temperature for heat treatment of stainless steel wire differed between investigations.[10-15] However, the results of heat treatment seem to be on a continuum with the amount of stress relief desired. Stress relief increases up to a point, as the temperature increases. For virtually all residual stresses to be relieved, austenitic stainless steel must be heated to 1,650°F. At temperatures below this only partial stress relief occurs.[16] The disadvantages of this high temperature stress relief are reduced mechanical properties and decreased corrosion resistance.

Marcotte's research indicates that for wire springs of .016 inch stainless steel, heat treatment of 750°F for 11 minutes significantly improves the elastic spring back. He felt that maximum spring back was a useful parameter to determine the characteristics of a spring. Note:

$$\triangle \text{Max} = \frac{\text{Fmax}}{\text{rate}}$$

where $\triangle$ Max is the maximum spring back, Fmax is the maximum force that can be placed on the spring without permanent deformation, and rate is the load deflection rate.[14] Burstone states that the optimal spring for tooth movement is one that has a high maximum spring back. In other words, the spring has a high amount of elastic force and a low load deflection rate.[5]

Stainless steel has many qualities that have made it popular for orthodontic use. The qualities include: 1) hardness, 2) high tensile strength, 3) resistance to corrosion and discoloration, 4) relatively easy to solder, 5) moderately easy to manipulate and bend. However, when fabricating orthodontic springs or making bends in a continuous archwire, stainless steel cannot withstand much cold working. The wire will fatigue more rapidly than the bending of some other alloys, especially when forming loops.[17] Because it is so stiff, the wire has a tendency to roll when the clinician is fabricating loops and bends. (For stainless steel composition see Table 1).

In recent years, various chrome cobalt and closely related alloys have found wide application in orthodontics. (For Elgiloy composition see Table 2). Elgiloy is one of these alloys. It was originally developed by the Elgin National Watch Company to be used for mainsprings in watches. Although chrome cobalt wire is similar in appearance to stainless steel, it has several claimed advantages: 1) greater resistance to fatigue and distortion, 2) longer function as a resilient spring, 3) easily heat treated to remove internal stresses and increase spring performance, 4) easily soldered without annealing, 5) simple electrolytic polishing.[17] Waters' research noted that for ease of formation a wire should have low elastic strain and a low amount of stored energy. Elgiloy meets these requirements, and in addition, its elastic properties are improved by heat treatment.[18] The Elgin National Watch Company stated that when comparing the physical properties of elgiloy to watch spring steel, it is superior. It is superior by the following percentages:

1) 275 percent in resistance to set, 2) 100 percent in fatigue resistance, 3) slightly higher yield strength, ultimate strength, and hardness. However, before one draws the conclusion that this is a "wonder wire", there are some disadvantages: 1) this alloy exhibits a greater degree of work hardening than stainless steel for the same amount of wire manipulation, 2) insulation of loops may be required to avoid overheating of the loop system when heat treating, 3) the coloration from oxidation after heat treatment needs to be removed.[17] Indeed, one of the disadvantages of heat treatment of any of the three wires tested is the coloration changes.[19,20]

Studies with the chrome cobalt alloy have been carried out by various researchers in recent years. In 1976, Waters reported heat treatment improved the elastic properties of .016 inch stainless steel and Green Elgiloy. The improvement was significantly greater for Green Elgiloy.[19] Further testing by Waters in 1981 showed that for heat treated Green Elgiloy, there were significant improvements. These improvements may vary somewhat from different batches of Green Elgiloy.[21]

Fillmore noted in his research that after heat treatment of 900°F for 5 minutes, .016 X .022 Blue Elgiloy required 272 grams of force before 0.1 millimeter of permanent deformation occurred. The increased resistance to permanent deformation was a 95 percent improvement over nonheat treated samples. A 174 percent improvement was attained when the samples were heat treated at 1200°F.[22]

With the advancement of electronic technology, methods for measuring force application and decay of that force were developed. Lacy's study developed methods and equipment for the measurement and recording of forces produced by orthodontic wires when they were loaded. He studied sample wires of .016 X .016 inch Blue Elgiloy, Permachrome Standard and Multiphase. His study showed that the equipment with specific modifications was accurate for continuous measurement of forces produced by orthodontic wire over any given period of time.[23]

Corbett's research utilized the methodology developed by Lacy and his work tested the force relaxation in .016 X .016 utility arches made from Blue Elgiloy, Permachrome Standard and Multiphase. He concluded from the results of his study the following: 1) The three types of wires gave approximately similar relaxation rates when loaded to 50 grams, in the unheated samples. Heat treatment of the three wire types yielded improvement for all samples. 2) Most of the force relaxation for the orthodontic wires occurred by the end of 48 hours. At the end of one week the force relaxation was negligible. 3) Intrinsic properties of the nonheat treated wires tested were apparently responsible for 9 - 11 percent force relaxation over a one week period. 4) Heat treatment of the wire samples improved the elastic properties so that the force loss was decrease 50-80 percent.[24]

Clawson's research investigated the amount of force loss in closed helical retraction springs. Wire samples consisted of .016 X .016 Blue Elgiloy, Permachrome Standard and Multiphase. The results indicated the following: 1) The three types of wires gave approximately similar relaxation rates when loaded to 150 grams, in the non-heat treated samples. 2) Most of the force relaxation for the orthodontic wires occurred by the end of 24 hours. At the end of one week the force relaxation was negligible. 3) Heat treatment of permachrome standard wire samples improved the loss of force by 50 percent. However, the heat treatment of the blue elgiloy and multiphase retraction springs increased the amount of force loss! Clawson postulated that perhaps the temperature was excessive. He suggested that when the wire was placed in the oven, the automatic thermostat over-corrected to compensate for drop in temperature when the door was opened to place the samples inside. It is possible that this annealed the wire when it overheated.[25]

Another interesting study was done by Lane and Nikolai.[26] They tested the effects of stress relief on stainless steel wire loops. Both oven treatment and electric-current stress relief were tested. The size of wire was much larger and only stainless steel wires were tested. Their observations were: 1) Stress relieving will increase the elastic range where maximum activation is decreased by the elastic limit of the loop. 2) Clinicans who choose to stress relieve may be led to use the electric current procedure because of its comparative ease and low cost.

Some researchers have felt that heat treatment by electrical resistance may be inaccurate because the terminals may act as heat sinks and provide uneven heating.[19] Others suggest that because the wire is contacting areas where it is looped over on itself, this will cause that area of the wire to overheat; especially those of the chrome cobalt alloys. Some researchers recommend insulating against this by laying a small piece of wet cotton over the loop.[17]

The purpose of this study, restated again, is to answer the following questions:

1. What is the amount of force loss in closed helical retraction springs of nonheat treated and heat treated samples?
2. Is stress relief for closed helical retraction springs necessary or advisable?
3. Does the type of wire influence that decision?
4. Does the method of heat treatment for Blue Elgiloy yield significant differences?

MATERIALS

Selection of Wire

Three types of .016 X .016 wires were tested in this study. Because the wire configuration and dimensions were the same, the force lost after activation was dependent on the different alloys and their intrinsic characteristics. The three types of wires tested were:

1. Permachrome Standard - A stainless steel
2. Multiphase - A cobalt-nickel-chromium alloy
3. Elgiloy - A cobalt-chromium-nickel alloy

Because there could be some variation between different wire batches, the sample wires were taken from the same batch for each of the respective wires.

Forty-four wire samples were bent in a closed helical loop configuration because part of this study is a continuation of previous research based on this type of retraction spring. Moreover, this loop design is easily reproducible for standardization. An abrupt angle was bent at one end of the retraction spring. This end was attached to the load cell. The working length of 31 millimeters was used because in the anterior-posterior dimension the buccal segment of cuspid, first and second bicuspid and first molar is 31 millimeters. An additional 7 millimeters was used to hold the wire in the apparatus. Figure 1 illustrates the dimensions of the wire samples.

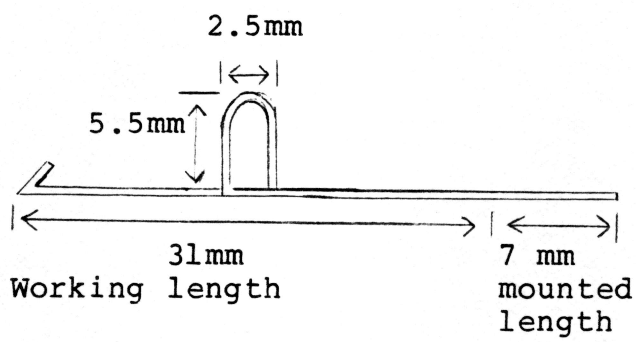

Figure 1 Helical Closing Loop Retractor

Standardization was obtained by using the second step of a Nance loop forming plier. This step forms a loop that is 5.5 millimeter in height and 2.5 millimeter wide. The completed wire was checked against a millimeter scale.

The configuration of the helical closing loop wire sample has the advantage of having a stable configuration when compared to an opening loop. It has increased resistance to further deformation because the loop is compressed or wound up as it is activated.[15,18] (Figure 2)

Figure 2 Opening Versus Closing Loop

Four wire samples were bent in a Hilgers design. Standardization was obtained by using the second step of a Nance loop forming plier and the first and second steps of a Tweed loop forming plier. The working length of 31 millimeters was used in addition to a 7 millimeters mounted length.

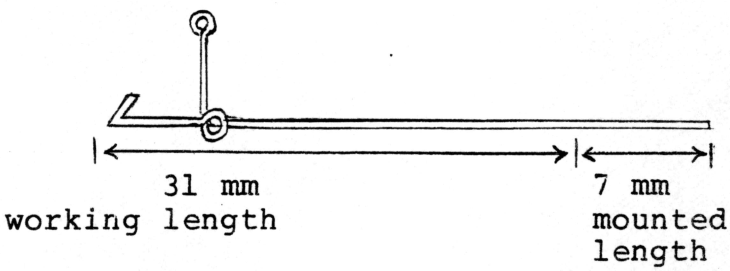

Figure 3 Hilgers Retractor

Apparatus

A constant voltage transformer (Figure 4) was used to regulate the input voltage to the Hewlett-Packard logging multimeter (Figure 5) and the separate Hewlett-Packard power supply. (Figure 5) The regulation of accuracy set for the constant voltage transformer was 1 percent or less with a total line variation of 15 percent. The Hewlett-Packard power supply was set at 14 volts. This unit also regulated the electrical current and eliminated variations in electricity from the wall outlet.

The constant voltage from the power supply was wired to four electrical load cells that were rated for a maximum load of five pounds. (Figure 6) When the load cell receives the input voltage from the power supply, it proportions it in relation to the force exerted. In this experiment, a modification of the system was made with the use of potentiometers (Figure 7) that divided the current down and fine-tuned the apparatus even further. After the load cell receives an input current, it then delivers an output current to the Hewlett-Packard logging Multimeter. The multimeter interprets the current and records the force as a measurement in millivolts. The millivolt reading is on a digital display that can be selected to scan all readings, or any combination whenever the operator desires.

The logging multimeter could be programmed to produce a thermal paper printout with the time and data from each of the lead cells. This feature allowed for continuous monitoring of the experiment for each of the one week test periods.

The device used to hold the retraction springs was originally designed by Lacy and modified by Clawson. Figures 8 and 9 show the load cell device. In this experiment, a stand was built to accommodate all four load cell devices, and allow easy calibration of each load cell. The entire set up was placed on 1/2 inch styrofoam to provide a shock absorbant material. In addition, a styrofoam cover fit over the load cells and stand to produce an even temperature chamber and eliminate drafts.

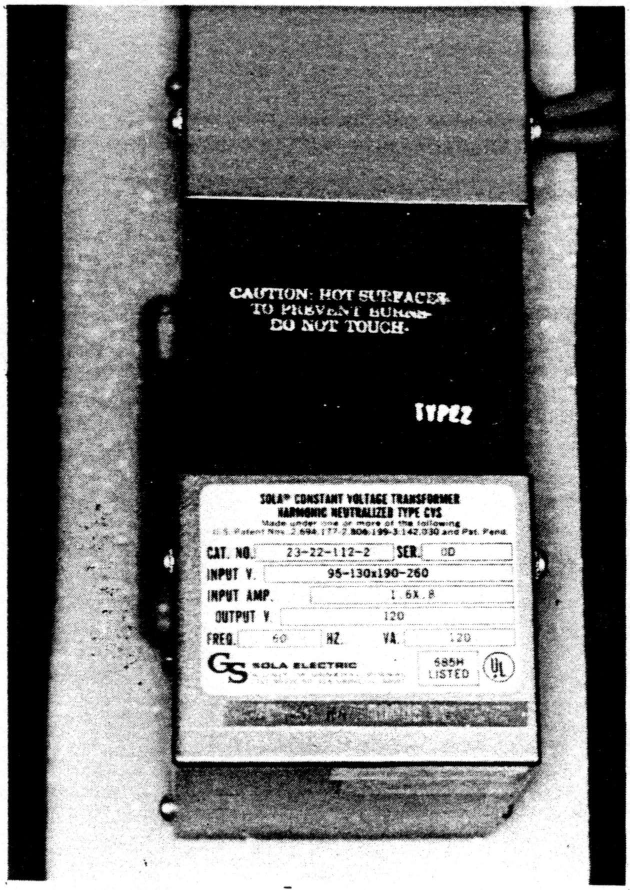

Figure 4. Photograph of Sola Constant voltage transformer Model CVS 12

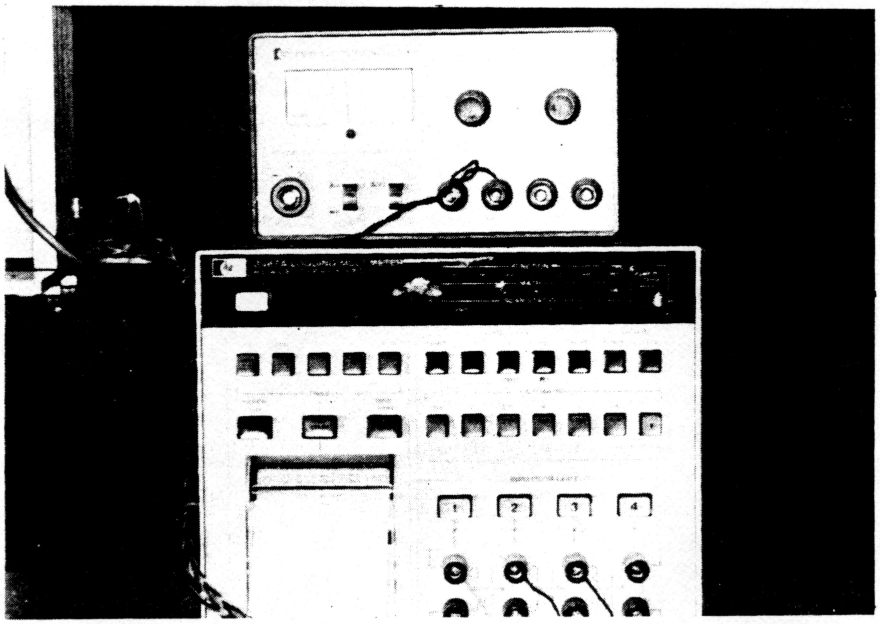

Figure 5. Photograph of Hewlett-Packard Logging Multimeter and power supply Model 3467A and Model 6234A

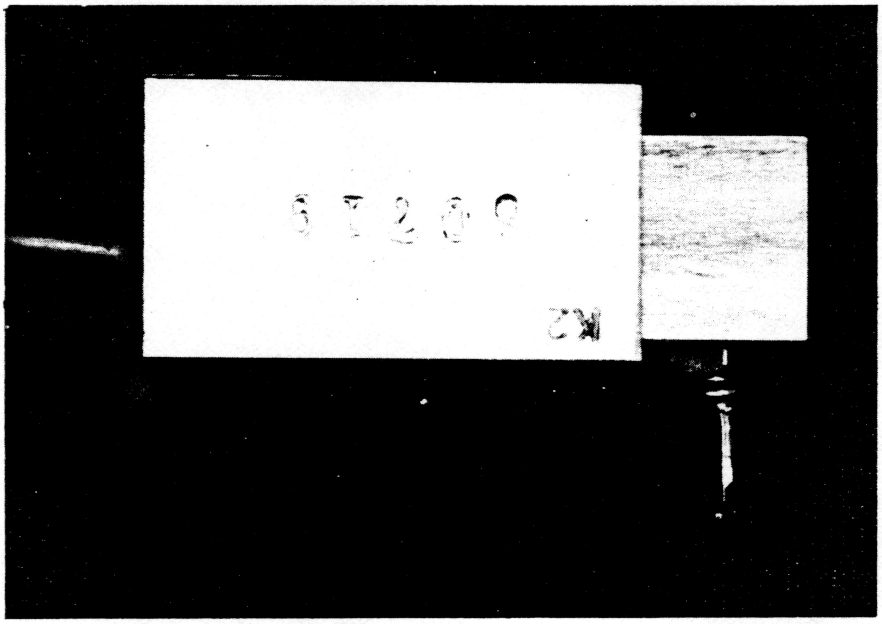

Figure 6 Photograph of Load Cell - Model K 2

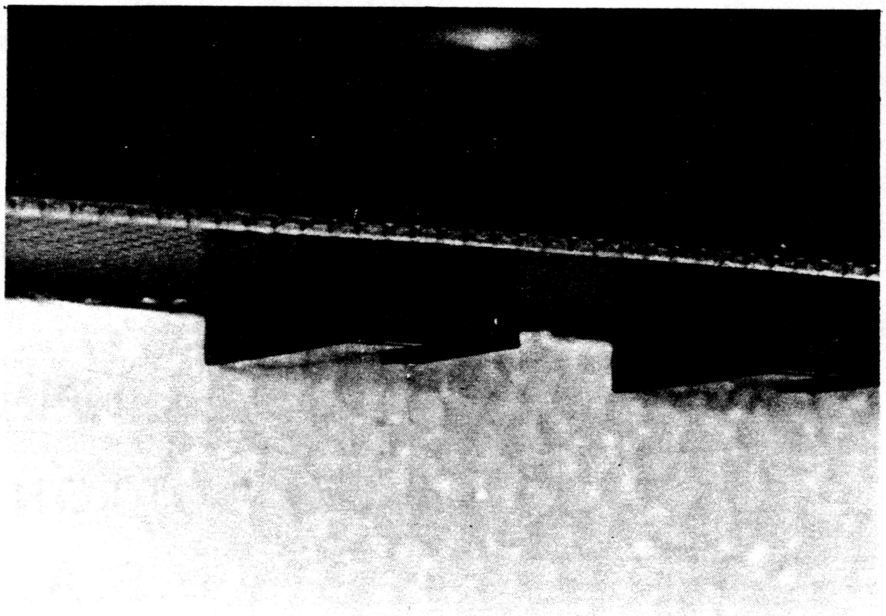

Figure 7. Photograph of Potentiometers

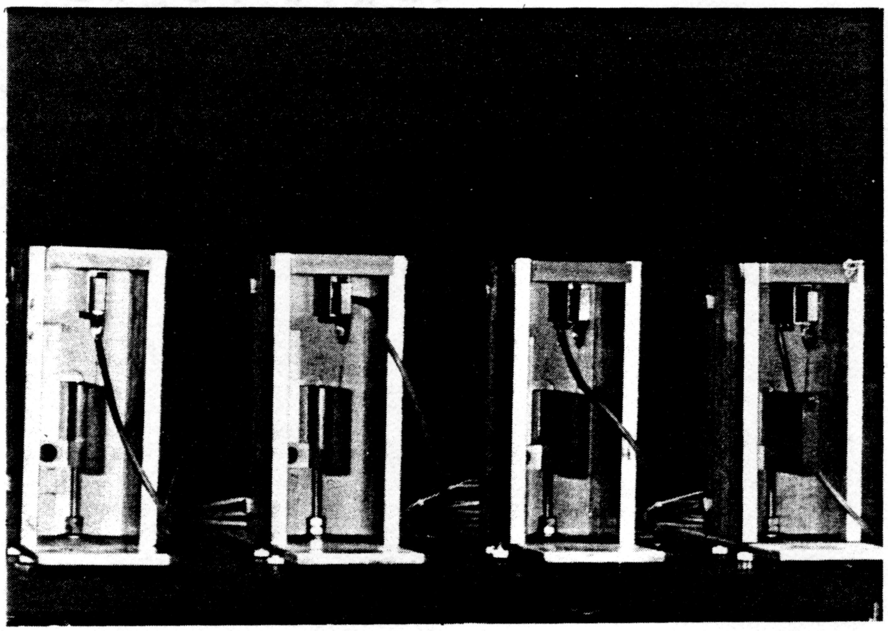

Figure 8. Photograph of Load cell device and stand.

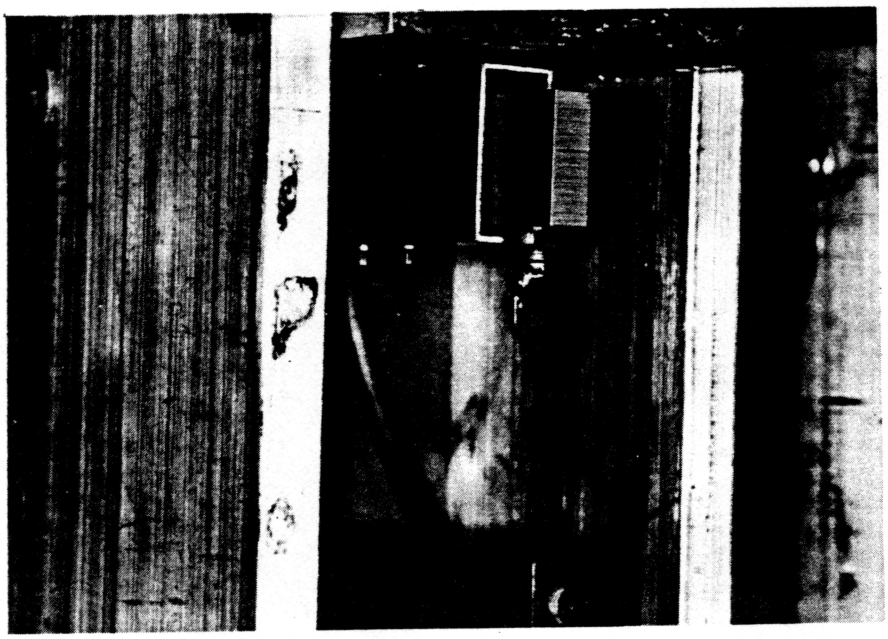

Figure 9. Photograph of Load cell device with wire sample in place.

METHODS

Validity Test of the Equipment

The load cells were tested with a standard weight of 150±.05 grams. During the one-week tests the logging multimeter recorded tri-hourly readings. At the end of the test period it was noted that there were significant variations in the recordings. Because standardized 150 gram weight were used, the weight was not changing. It was postulated that the load cells were sensitive to changes in room temperature, and were the source of variation. A styrofoam cover was built to fit over the load cells to produce an even temperature chamber.

With the temperature chamber in place, new standardized weight tests were run. Afterwards, eight preliminary wire samples were tested. However, a significant variation was still noted. The operating manual stated that the machine would drift 10 counts at the last decimal place, and recommended resistive dividers to obtain the necessary accuracy on the 20 mV range. Specifically at +.005 the reading could be +.015 or -.005. For that reason, potentiometers were added to circuit to divide the electrical current. For example, a reading of

.150mV was converted to 1.500 mV Validity testing proved this adjustment to be very accurate.

Preparation of the Wire Samples

A total of forty-eight wires sampled were fabricated and randomly selected for testing.

Type of Wire	Sample Size	Type of Stress Relief
Permachrome	5	None
Permachrome	5	Oven
Multiphase	5	None
Multiphase	5	Oven
Blue Elgiloy	9	None
Blue Elgiloy	5	Oven 900°F
Blue Elgiloy	5	Oven 1000-1200°F
Blue Elgiloy	5	Elec. current & flash paste
Blue Elgiloy	9	Cigarette lighter & flash paste

In addition to the forty-eight samples tested, eight samples of the three wire types were tested. These were used in pilot studies before the potentiometers were installed.

The methods of heat treatment are summarized as follows:

Type of Wire	Type of Stress Relief	Reference
Permachrome Standard	Electronically controlled porcelain oven at 750°F for 11 minutes.	Marcotte[13]
Multiphase	Electronically controlled porcelain oven at 900°F for 30 minutes	Am Orthod.[20]
Blue Elgiloy	Electronically controlled porcelain at 900°F for 5 minutes	Fillmore[22] Rocky Mt Orthod.[17]
Blue Elgiloy	Electronically controlled porcelain oven at 1000 - 1200°F. Increase 50°/minute	Clawson[25]
Blue Elgiloy	Electric current with flash paste	Rocky Mt Orthod.[17]
Blue Elgiloy	Cigarette lighter and flash paste	Rocky Mt Orthod.[17]

Preparation of the Apparatus

Prior to inserting the wire sample, the logging multimeter was zeroed and a zero 1 reading was recorded. Next, the standardized 150 gram weights were suspended from the load cells and the following readings were taken: 1.500mV = 1.500 grams. After this was done the weights were removed, and the logging multimeter was zeroed. Now the apparatus was ready to receive the wire samples.

Placement of the Wire Sample

The wire sample was marked with the proper working length of 31 millimeters. First the tie back section was hooked on the load cell. Next the platform with the vise set screw was raised to place until the working length of 31 millimeters was attained and the wire was hanging passively. Once this was obtained, the wire was secured in place by tightening the set screw, and securing the wire in a locked position. The logging multimeter was zeroed and then 150 grams of activation was applied to each sample. The activation of 150 grams was chosen because of research done by Brian Lee.[27,29] He proposed from the results of his studies, that 200 grams per square centimeter of root surface was the most desirable force. For cuspid retraction, this would be approximately 150 grams, because the average root surface is equal to .75 centimeter.[2]

Length of Trials

Corbett[24] and Clawson[25] found that the loss of force occurred most rapidly within 48 hours and by the end of one week, further force relaxation was practically negligible. Preliminary wire sample showed similar results so the samples were only tested for one week.

Validity Test of Apparatus at the End of Each Trial

At the end of each trial the wires were removed and the logging multimeter was tested for drift, by checking the values against the manufacter's specification of 10 counts at the third decimal place. The multimeter was zeroed and the 150 grams weights were placed on the load cells as a final check.

Statistical Analysis

In this research, both descriptive and inferential statistics were used to arrive at the final conclusions. A computer package known as the Statistics Package for the Social Sciences (SPSS) was utilized for statistical findings. A general linear hypothesis was used to test for significance.

The independent variable was the initial force. Dependent variables were: 1) load cell, 2) heat treatment, 3) wire type, 4) wire design. A "p" value of $<.05$ was chosen to indicate significance.

RESULTS

The mean force loss for non-heat treated and heat treated wire samples are shown in Table 1. All three wire types lost more force in the non-heat treated state. The mean force loss was the greatest for Blue Elgiloy in the non-heated condition. Blue Elgiloy's mean force loss over the seven day period was 11.9 grams. The Blue Elgiloy wire sample that exhibited the most force loss over the test period was 25.6 grams. The mean force loss for non-heat treated Permachrome and Multiphase was 5.8 grams and 9.4 grams, respectively. (Table 2).

The "p" value for heat treatment of the three types of wires was <.001. The analysis of the main effects of heat treatment, wire type, and load cells resulted in a "p" value of <.001 for heat treatment. (Tables 3 & 4)

An analysis to compare the force lost of a helical closing loop versus a Hilgers retractor yielded a "p" .684. (Table 5) The distances for activation of 150 grams was greatly different. In .016 X .016 Blue Elgiloy samples, the helical closing loop could be activated 3/4 of a millimeter before obtaining 150 grams of force, whereas, the Hilgers retractor could be activated 1 1/4 millimeters, and the Ricketts retractor could be activated 1 1/2 millimeters before obtaining 150 grams of force. For further comparison, grey chain was activated 1 1/2 millimeters, and a force of 195 grams was obtained. Table 6 lists the designs, distance for activation, and the resultant force. It was observed that the grey chain's force loss was 66 grams or 34 percent loss from the initial force, within 24 hours.

The five methods for heat treatment of Blue Elgiloy reveal that all of the methods will yield similar results. ("p" = .340). (Table 8). In testing the oven heat treatment method, it was determined that the opening of the oven door for approximately 10 seconds to place in the wire samples, would cause the thermostat to fire up the oven and compensate for the loss of heat. The oven temperature would rise 40 degrees Fahrenheit before shutting off. Graphs 1 and 2 show differences in mean force loss in the present study when compared to Clawson's research.

DISCUSSION

As a result of previous research, a method for monitoring force loss over a given time has been pioneered at Loma Linda University. This study agrees with the basic conclusions drawn from Corbett's[24] and Clawson's[25] research, in that heat treatment will decrease the amount of force loss. However, because of modifications within the system by the addition of potentiometers, the results were able to be fine tuned to a greater degree of accuracy. For this reason the mean force loss of this study differed from Clawson's research. (See Graph 1) In addition, Corbett's[24] and Clawson's[25] study did not allow for an equal value readout on each load cell. The potentiometers enabled the readout of each load cell to be similar.

This study showed the most force loss occurred with non-heat treated Elgiloy when comparing it to Permachrome and Multiphase in a similar condition. However, when Blue Elgiloy was heat treated, it was better than Permachrome and Multiphase in a similar condition. These findings agree with Corbett's[24] research, but disagree with Clawson's[25]. There are three possible reasons why

Clawson's results differ. They are the following:

1. The temperature to heat-treat the Blue Elgiloy was 1200°F. Fillmore[22] observed that for Blue Elgiloy, heat treatment at 900°F allowed the wire to withstand a force of 272 grams before the wire was deformed. Heat treatment at 1200°F allowed the wire to withstand a force of 383 grams. Since the increased temperature resulted in a "stronger wire" the temperature of 1200°F for heat treatment was chosen in Clawson's study[25]. However, if the ideal force for cuspid retraction is 150 grams,[27] it seemed logical to seek the improvement from the 900°F heat treatment level. The spring will still withstand a force of 272 grams before deformation.
2. The length of time for oven heat treatment was 5 minutes at a constant temperature. Clawson's study[25] found that at 1200°F for 5 minutes, Blue Elgilcy actually lost more force than if it were not heat treated. He postulated that the opening of the oven door caused the oven to overcompensate for the loss of heat. For that reason, he placed the wires in the oven at 1000°F and then brought the temperature up to 1200°F. This study quantified the amount of

temperature change that occurs when the door is open to place the samples inside. The oven temperature increases 40°F when the door is open for 10 seconds.

3. In Fillmore's study.,[22] the wire design did not cross over on itself. In contrast, the wire design of Clawson's study[25] did. The area where the cross over occurs may heat up first and radiate heat. This would cause the wire to overheat in that area. In addition, Fillmore's study[22] involved .016 X .022 and .018 wire samples and Clawson's study[25] involved .016 X .016. The smaller size diameter wire may heat up quicker than a larger diameter wire.

A few studies have been done on the design of retraction springs,[5,26,27] but they have either been limited to the effects of heat treatment of stainless steel, or have not investigated various wire designs. The present method has continuously monitored force loss of two different designs over a seven day period.

The results of testing a helical closing loop versus a Hilgers retractor indicates that there is no statistical difference between the two. Each design will lose a similar amounts of force. This is a result of one basic

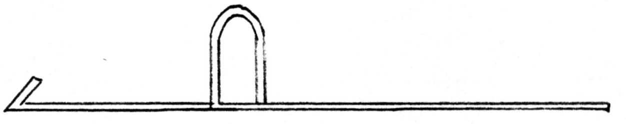

Figure 10. Helical Closing Loop

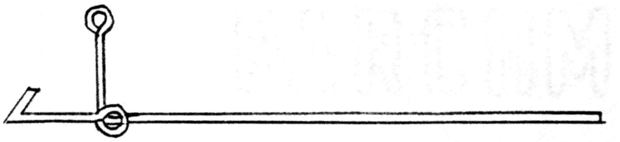

Figure 11. Hilgers Retractor

similarity. Each design has a 90° bend. This bend has the potential to open up when the wire is activated. The strengthening of this bend by heat treatment or a different design may be critical to the reduction of force loss.

The type of heat treatment for retraction springs made of Blue Elgiloy will not yield significantly different results. This is an important discovery. Some researchers have suggested that resistance treatment and a flame from a cigarette lighter may not evenly heat the wire. They have suggested that loops within a wire design will overheat and insulation may be needed.[17,19] By assuming that the loops would heat up more quickly, this research has placed flash paste on the area where the wire crosses over itself. For the Hilgers retractor, this would mean that the flash paste would be placed in two places. It was noted that the two locations flashed almost simultaneously. As a result, only one location is necessary to monitor the proper heat treatment. While it is true that the flame from a cigarette lighter will not heat the wire evenly unless you move it up and down the wire, it is only important to heat the 90 bends as was previously noted.

CONCLUSIONS

1. In the non-heat treated state, Blue Elgiloy, Multiphase and Permachrome did exhibit force loss. There is no statistical difference in the amount of force loss between the three types of wires ("p" value .166). However, there is a trend ranking the amount of force loss. Without heat treatment Blue Elgiloy had greater force loss than Multiphase and Permachrome. Most mean force loss = Blue Elgiloy > Multiphase > Permachrome.
2. Stress relief via heat treatment did result in a significant improvement in Blue Elgiloy, Multiphase and Permachrome. ("p" value .000).
3. After heat treatment Blue Elgiloy had less force loss than Permachrome and Multiphase. Least mean force loss = Blue Elgiloy < Permachrome < Multiphase.
4. The method of heat treatment (oven, resistance and cigarette lighter) for Blue Elgiloy did not yield significant differences. ("p" value .340).
5. There is no significant difference in the amount of force loss when comparing a helical closing loop and a Hilgers retractor in the non-heat treated state.

6. Wire design is critical to the distance for activation. A Ricketts retractor has the greatest distance for 150 grams of activation. A helical closing loop has the least. Distance for activation = Ricketts > Hilgers > helical closing loop.

7. When activated 1 1/2 millimeters, grey chain will yield 195 grams of force. At the end of 24 hours the remaining force is 129 grams.

SUMMARY

Orthodontic wire may be heat treated to relieve residual stresses resulting from the formation of bent configurations. This study utilized electronic equipment to detect and record the initial amount of activation force, and the amount of force lost due to the intrinsic properties of the wire. The information was gathered at three hour intervals over fifteen one-week periods. The data were statistically analyzed by a computer to determine means and standard deviations. A general linear hypothesis was utilized to test covariants and the main effects.

A total of forty-eight wires were tested. Closed helix retraction springs fabricated from .016" X .016" Blue Elgiloy, Permachrome Standard, and Multiphase were tested in non-heat treated and heat treated conditions. Hilgers retraction springs fabricated from .016" X .016" Blue Elgiloy were tested in a non-heat treated state. Activation force for helical closing loop, retractors, Ricketts retractors, and Hilgers retractors and grey chain were observed.

The data indicated that without heat treatment Blue Elgiloy had greater force loss than Multiphase and Permachrome. However, after heat treatment of the three types of wires, Blue Elgiloy had less force loss than Permachrome and Multiphase. The effects of heat treatment for the three types of wires were statistically significant. Three methods for heat treatment of Blue Elgiloy were tested. Heat treatment of Blue Elgiloy using an oven, resistance or cigarette lighter, revealed no statistical differences.

The wire design of a helical closing loop versus a Hilgers retractor did not significantly decrease the amount of force lost in non-heat treated Blue Elgiloy. However, the wire design did affect the distance for activation. A Ricketts retractor had the greatest distance for activation of 150 grams. Hilgers retractor had intermediate distance, and a helical closing loop had the least distance for activation. Grey chain activated 1 1/2 millimeters exerts a force of 195 grams. The force of activation decreased 66 grams at the end of 24 hours.

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APPENDIX

	Permachrome Standard				Multiphase				Blue Elgiloy			
	Initial		Final		Initial		Final		Initial		Final	
	$\bar{X}$	S D	$\bar{X}$	S D	$\bar{X}$	S D	$\bar{X}$	S D	$\bar{X}$	S D	$\bar{X}$	S D
No Heat Treatment	1.502	.006	1.444	.016	1.500	.003	1.406	.036	1.502	.004	1.383	.058
Heat Treatment (Oven)	1.505	.002	1.492	.020	1.504	.004	1.490	.013	1.502	.008	1.495	.005

Table I Mean Force Loss in grams over a seven day period
.01 = 1 gram = 1%

	Permachrome Standard	Multiphase	Blue Elgiloy
NO HEAT TREATMENT			
Mean force loss at the end of 7 days	5.8 grams	9.4 grams	11.9 grams
Wire sample that had the most force loss at the end of 7 days	6.6 grams	13.3 grams	25.6 grams
HEAT TREATMENT			
Mean force loss at the end of 7 days	1.3 grams	1.4 grams	.7 grams
Wire sample that had the most force loss at the end of 7 days	5.1 grams	4.0 grams	2.1 grams

Table 2 Force Loss in grams over a seven day period

URCE OF VARIATION	Sum of Square	D F	Mean Square	F	"P" Value
variates					
itial Value	.000	1	.000	.139	.712
in Effects					
Wire	.005	2	.002	1.918	.166
Heat Treatment	.052	1	.052	39.778	.000
Way Interactions					
Wire Heat Treatment	.005	2	.003	2.16	.141

Table 3 Main Effects of Wire and Heat Treatment

SOURCE OF VARIATION	Sum of Square	D F	Mean Square	F	"P" Value
Covariates Initial Value	.01	1	.001	.914	.354
Main Effects Wire	.003	2	.002	1.237	.318
Cell	.003	3	.001	.732	.549
Heat Treatment	.037	1	.037	30.033	.000
2-Way Interactions	.014	11	.001	1.064	.445
Wire Cell	.005	6	.001	.670	.675
Wire Heat Treatment	.002	2	.001	.88	.433
Cell Heat Treatment	.004	3	.001	1.050	.399

Table 4 Main Effects of Wire, Cell and Heat Treatment.
2-Way Interactions

SOURCE OF VARIATION	Sum of Square	D F	Mean Square	F	"P" Value
Covariates Initial Value	.001	1	.001	.164	.699
Main Effects Wire Design	.001	1	.001	.182	.684

Table 5 The Effects of Wire Design: Closing loop versus
a Hilgers retractor

Design	Activation Distance	Force
Closing Loop	3/4 mm	150 grams
Hilgers Retractor	1 1/4 mm	150 grams
Richetts Retractor	1 1/2 mm	150 grams
Grey Chain	1 1/2 mm	195 grams

Table 6 Design, Activation Distance and Force

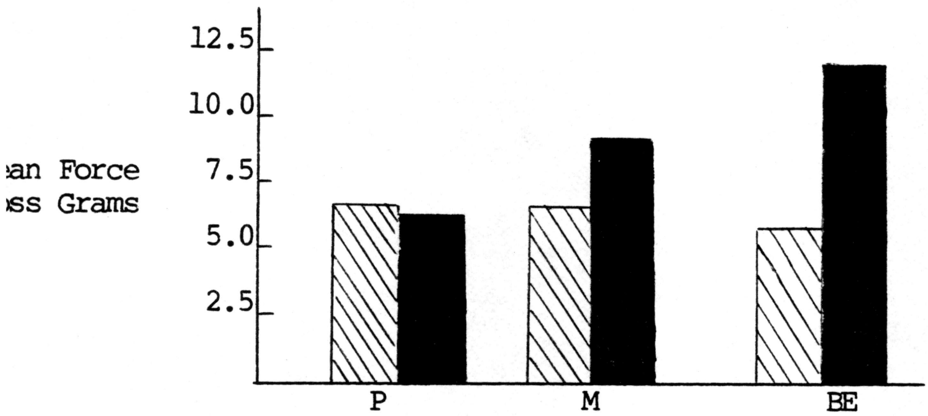
BLUE ELGILOY

	Initial X	Initial S D	Final X	Final S D
No Heat Treatment	1.502	.004	1.383	.058
Heat Treatment Oven 900°F 5 minutes	1.502	.008	1.495	.005
Heat Treatment Oven 1000-1200°F 5 minutes	1.503	.004	1.496	.004
Heat Treatment Resistance and Flash Paste	1.500	.003	1.485	.032
Heat Treatment Cigarett Lighter and Flash Paste	1.501	.001	1.473	.018

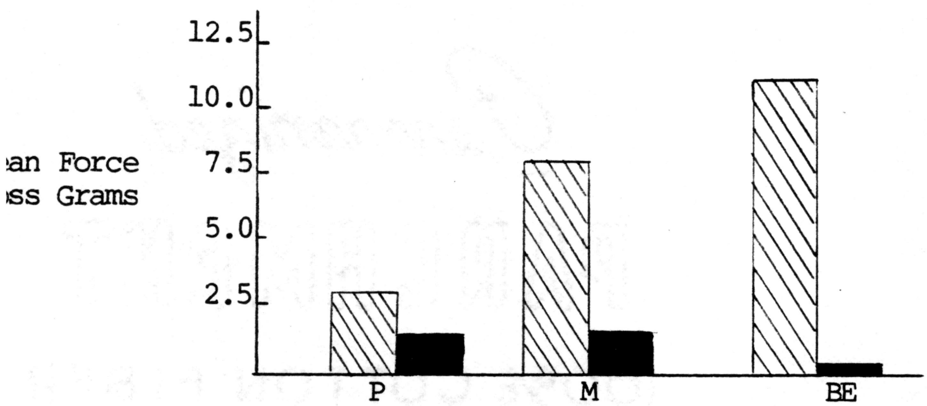
Table 7 Force Loss in grams over a seven day period

SOURCE OF VARIATION	Sum of Square	D F	Mean Square	F	"P" Value
Covariates Initial Value	.001	1	.000	.691	.420
Main Effects Heat Treatment	.001	3	.000	1.216	.340

Table 8 The effects of the four different methods of heat treatment



Graph 1 Mean Force Loss - No Heat Treatment



Graph 2 Mean Force Loss - Heat Treatment