In vitro Study

of the

Force Decay of Ligation Type Elastomeres

used in

Orthodontic Space Closure

by

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INTRODUCTION

Since the introduction of elastomeric materials, their use in space closing mechanics has grown quite popular. Several design variations have been proposed: continuous chains of either open or closed loops ligated to each bracket in the arch, or segmented in each quadrant, or 2, 3, or 4 loop chains stretched from attachments on either side of an extraction site. Research has been quite extensive as to the rate of force decay and environmental influences on these force decay rates for the elastic modules.

The basic goals of space closure mechanics have been to provide a relatively simple mechanism which will generate forces in an adequate range and for sufficient time to translate the teeth across the extraction space. Ideally, the force must be maintained for three to six week intervals depending on the clinicians philosophy of patient visit intervals.

An interesting mechanism of providing space closure has been proposed by Dr. R.P. McLaughlin[1]. In this system a single elastomere of the ligation type is used as the force system. The elastomere is attached to an auxiliary hook and activated by stretching and securing it across the extraction site with a steel ligature. Dr. McLaughlin feels activations of 2 - 3 times the initial length routinely result in 0.5 to 1.5 mm of space closure per four week interval.

The evidence for effectiveness of this system appears to be empirically based and extrapolated from data on elastomeric chain module data. It appears no studies have been published on the nature of the force decay rate for single elastomere modules. The purpose of this study was to evaluate the force decay rate of single elastomere modules when utilized for space closure in the method recommended by Dr. McLaughlin. Three manufacturer's products were tested over a four week time span: Unitek S2 posterior separators, Ormco .120" Power O modules, and GAC .120" Elastoring modules.

LITERATURE REVIEW

In 1970 Andreasen and Bishara[2] evaluated Alastik chain materials. Force decay under in vitro test conditions were evaluated. Five test conditions - room temperature air, water, and saliva, as well as 37^{oC} air and water were compared to 37^{oC} saliva for effects on force decay. Compared to 37^{oC} saliva, no statistical difference for testing was reported with only the 37^{oC} water medium. This was then selected for the remaining force decay tests. These tests evaluated C1 Alastik chains stretched to five separate, fixed distances, representing typical first molar to first molar lengths. They found the force decay at one hour to be 56%, 74% at 24 hours and 82% at 3 weeks. Based on these data the authors concluded initial force decay occurs rapidly then slows to a nearly constant rate. Also, initial force activations should be approximately four times the desired terminal force to compensate for the force decay of the first 24 hours.

In the same year, Andreasen and Bishara[3] also reported on studies of Unitek's Alastik "K" modules. Stretch distances were made to be representative of second molar to mesial of the cuspid distances. The methods of testing were exactly those of the first study. Mean pooled data force decay for the KX modules were as follows: 45% in first hour, 55% at 24 hours, and 67% at the end of 3 weeks. Also noted in the study was a lack of quality control in the manufacture of early modules seen by the large range for the standard deviation of the Alastiks tested: 14.6 grams to 130.4 grams. The authors concluded that while force production was variable, the absence of patient compliance probably would overcome this. Ultimately though, questions remained as to the effectiveness of this system as compared to other systems for cuspid retraction on a continuous arch wire.

In 1975, Hershey and Reynolds[4] studied the effects of tooth movement on the force of decay rates of three manufacturer's products. 540 chain modules were tested on a moveable framework which allowed 0, 0.25 mm, 0.5 mm of simulated tooth movement per week. Various interbracket distances, ranging from 12 to 34 mm were utilized and testing over a six week period was done with the modules in a 37°C water medium. Unitek Alastik gray and clear chain, Ormco Power Chain and links, and TP Elast-o-chain were studied. At four weeks time, the effects of tooth movement were as follows: 40% of the initial force remained if zero closure occurred, 32% remained with .25 mm per week closure, and 25% remained with .5 mm per week closure. With .5 mm closure per week the force decay rates were unrelated to the initial forces. That is, high (average pooled data, 573 grams) or low (average pooled data, 284 grams) initial forces resulted in similar decay patterns and equal forces at four weeks. Between manufacturers, Alastik chains retained a 6% higher initial force at 24 hours, but no difference was noted in remaining forces at 4 weeks. Again, variability of delivery of initial forces was noted. Alastik clear and TP Elast-o-Chain, as determined by average and standard deviation of initial forces, had significantly higher variability than Ormco Power chain or Alastik gray chain. The authors concluded: 1) Similar decay curves for all the products resulted in force differences which are probably clinically insignificant. 2) Forces can be generated which will be in the ranges of those reported by Smith and Storey[5], Reitan[6], Begg[7], Hixon[8], and Boester and Johnson[9]. 3) Initial forces should be well above 'optimal' levels to compensate for force decay and effects of tooth movement on force decay. 4) Elastic space closure mechanisms are viable for space closure due to more continuous force delivery (as compared to headgear or latex elastic models) and lower likelihood of producing extreme initial forces which may lead to undermining resorption and delayed tooth movement.

Wong[10] studied the force decay rates for Ormco Power Chain and Unitek C_2 Alastik Chain. Under constant elongation and immersion in a 37°C water bath, the Alastik double loop chains delivered higher initial forces than the Ormco double loop Power Chains (641 grams versus 342 grams), but showed higher loss of force at 24 hours, (73% loss versus 50% loss). The 24 hour force levels were equal for both products. From one day to 3 weeks an additional 6% loss in force occurred. The author speculated the high initial force delivered by the Unitek Alastik Chain (641 grams) may create more patient discomfort than the Ormco Power Chain (342 grams). Also, the remaining force levels at 21 days may be insufficient to move teeth. He also reported that prestretching the elastomeres 1/3 of their original length will help avoid the permanent water, and intraorally in 11 adolescent patients undergoing orthodontic treatment. In vitro testing consisted of 15 units of each module stretched on jigs to 28 mm and stored in the three media for three weeks. The relaxation pattern for these modules reflected a similar result to previously mentioned studies. That is, a substantial degradation immediately after activation, but then a more gradual decrease throughout the test period. A significantly different amount of decay was noted in comparing the in vivo test to modules tested in 37^{oC} air at 3 weeks. The in air modules showed the least amount of force decay, and deviated from the in vivo amounts within the first hour. Force decay was also noted to be less in the 37^{oC} water model than the in vivo test. A statistically greater rate of decay occurred in vivo after one day for the chain and 10 days for the module. However, at three weeks, the difference in force was found to be only 1.5 ounces and in light of initial load amounts deemed clinically insignificant. This therefore lends support to Andreasen and Bishara's recommendation of 37^{oC} water as a satisfactory testing medium in vitro[2].

Two studies were published in 1979 and both studied the effects of prestretching on force decay rates of elastomeric products. The first, by Brantley et. al[14], evaluated this using Unitek C spool chain and Ormco second generation Power Chain. The purpose was to determine if prestretching would effect a more continuous force delivery system. Four unit specimens were prestretched to 100% extension for times of 1 hour to 24 hours and 1 week. Modules were then applied to jigs to measure force decay rate or allowed to relax in room temperature air from 1 to 7 days before force decay tests were conducted. Force decay rates were recorded for these times as well as activation times of 1 and 4 hours, 24 hours and 1, 2, and 3 weeks. Modules were tested in 24^{oC} room temperature air and 37^{oC} distilled water. Several conclusions were drawn from their results. First, prestretching in 37^{oC} water delivered a more constant force delivery. However, the elastics needed to be used immediately to avoid relaxation effects. Second, prestretching in air was ineffective in delivering a constant force with subsequent use. Third, Unitek Alastiks delivered higher mean initial forces than the Ormco Generation II Power Chains, but after one hour the Ormco chains maintained a higher force throughout the remaining test period. Fourth, at three weeks time, no significant differences in force levels were found under any of the various test situations. Thus, the only difference in force levels occurred at the initial activation, and under carefully controlled conditions prestretching can reduce the force reduction rate without diminishing the long term force delivery capacity.

The second study was conducted by Young and Sandrik[15]. In this study prestretching was done quickly by hand to lengths of 14 and 23 mm using Unitek CK Gray and C2 Gray Alastiks. Force decay rates were then compared between the two prestretch samples and controls using an Instron machine with a 90 gram initial force. All modules were stored in 37^{oC} distilled water for the short 24 hour decay period. For comparison, one group of C2 Alastiks were subjected to heavy initial forces (181.4 grams). As with previous studies, force decay was found to be strongest in the first six hours with a gradually tapering after that. Other findings include the following: the prestretched CK chains were shown to have a significantly reduced force decay rate at a 99% confidence level. Forces remaining at 24 hours were about 22% greater in prestretched versus control samples. The C2 Alastiks showed no benefit to prestretching, versus controls. The heavy initial force group of C2 Alastiks showed a significant increase in the force decay rates over the lighter initial force controls. It was suggested from this that plastic deformation of the C2 Alastiks may occur with these heavy forces, which is contrary to earlier recommendations by Andreasen and Bishara who recommended stretching modules 3 - 4 times there intended load to compensate for the force decay. They concluded that extreme overextension to compensate for force loss could result in capillary bed ischemia and undermining resorption and prestretching of CK Alastiks Chains would increase the initial force loss to avoid this potential problem.

Doyle[16] evaluated Unitek C1 gray Alastik Chain under in vitro conditions meant to simulate typical chain and fixed orthodontic appliance conditions. Plexiglass models were used which held bands and attachments for first and second molars, second premolars, and canines, with extraction sites of 7 mm for the first bicuspids. Chain was stretched over buccal edgewise brackets and lingual attachments to simulate clinical usage. With a fixed stretch distance, Doyle showed a 36% force decay in initial force at 2 hours, 39% decay at 24 hours and 44% decay at four weeks. This corresponded to initial forces of 1346 grams, 2 hour mean forces of 868 grams, 826 grams at 24 hours, and 4 week forces of 748 grams. He concluded that the mean four week force would be sufficient to give orthodontic tooth movement and changing of the chains prior to four weeks was unnecessary.

Porter[17] evaluated the same material modifying the models to give simulated tooth movements of approximately 0.25 mm per week, for about 1 mm space closure in a four week period. The extraction site was reduced to 5 mm in this study. Additionally, Porter evaluated two manufacturing processes for this chain in terms of effects on force delivery. One process involved injection molding, the other, cutting of the chains from an extruded sheet of polyurethane. The two processes delivered statistically different initial and four week force levels at a 95% confidence level. The punched chain material delivered less mean initial force (986 grams) than the injection molded material (1057 grams), but a higher mean force at four weeks (264 versus 214 grams). In terms of force decay, this corresponds to 73% decay for the injection molded material, and 80% decay for the punched material. These reductions in force rates are slightly higher than those reported by Hershey and Reynolds[4]. Porter concluded that final force levels would be adequate for either type of chain in clinical use, even though a statistically significant difference was apparent.

DeGenova[18] evaluated the effects of thermacycling modules in vitro. Tests were conducted using both fixed stretch distances and simulated space closure models. All samples were stored in an artificial saliva medium. Controls were maintained at 37^{oC} while the test groups underwent twice daily thermacycling for 30 minutes with a dwell time of 30 seconds. The temperature range of 15^{oC} to 45^{oC} used was based on earlier published material which showed this to be the extreme temperature range of the oral environment when subjected to exposure of hot coffee and ice water[19]. The data collected suggests thermacycled modules exhibit less force decay over a 21 day period than control modules stored at a constant temperature. Also, simulated tooth movement resulted in a significant decrease in mean percent of force remaining at 14 and 21 days as compared to the fixed stretch controls. Three manufacturer's products were evaluated in this study, specifically, Rocky Mountain Orthodontics Energy Chain, Ormco Generation II Power

Chain and TP Elastochain. Analysis of standard deviations of initial forces delivered by the three manufacturers modules indicated an unpredictability of initial force delivery remained, as seen by the large range of the standard deviations. Long segments standard deviation range was 11.3 to 55.4, and for short segments the range was 13.2 to 27.4. The authors concluded thermal cycling better simulated oral conditions and would be better for in vitro testing than storage at a constant temperature. This was based on the increased force retention found with thermacycling. This, however, is in contradiction with previous work by Ash and Nikolai[13] who found increased force decay in vivo.

Brooks and Hershey[20] also studied the effects of heat and prestretching on force decay rates of elastomerics. Thermal cycling was described as "simulating a hot beverage." Samples were prestretched, then measured for force decay with a system that simulated tooth movement. They found a higher force decay rate with thermacycling versus controls stored at a constant temperature. This finding is similar to Ash and Nikolai. Additionally, the authors found prestretching the elastomeres somewhat counteracted the effects of heat on force decay rates. Comparison to in vivo samples was not done so it remains that storage of modules in water at a constant temperature simulating body temperature as described by Andreasen and Bishara is a valid method for in vitro testing elastomeres.

In 1989, Brown[21] reported on the force decay of two "second generation" elastomeric materials (RMO Energy Chain and GAC Chainette) compared to Unitek C1 Spool Chain. Force decay was measured over a four week period with four different fixed elongations of 23%, 93%, 205%, 346%. A 37^{oC} water bath was utilized for storing the modules, and an Instron machine for measuring the forces. She found the force decay to be positively correlated with initial force levels and percent elongation. However, for average percent force decay, prediction of final forces from percent elongation was unreliable as this varied with different initial forces, (or percent elongation). Mean pooled percent force decays were statistically different for the three brands, with the second generation chains exhibiting one-half as much force decay as the Unitek C1 Chain. She thus concluded the second generation chains were better suited for high continuous force mechanics and the

Unitek C1 Chain was better for low force mechanics.

McLaughlin[1] developed the elastic tie back as a response to disadvantages he felt were in alternative force systems. Elastic module chains provided variable forces, were difficult to keep clean and were sometimes displaced. Elastic bands depended on patient cooperation to be placed. The Pletcher Type wire coils[22] produced excessive forces which led to tipping of teeth into the extraction site and binding of the arch wire against the attachments. Also, hygiene was felt to be a problem.

McLaughlin felt with the straight wire appliance, more efficient sliding mechanics through the posterior brackets would allow decreased force levels to provide space closure. Thus moving from coil springs, closing loops, or overextended elastics to single elastic modules with ligature wires could reduce force levels from the 500 gram - plus levels. Activation of these elastic tie backs was said to be 2 - 3 mm or to twice its unrestricted dimension which would generate 100 - 150 grams of force. Proper levelling and alignment prior to the springs use was recommended. The light force of the elastic tieback would then give effective space closure with the use of .019 x .025 continuous arch wire in an .022 edgewise slot, on the order if 0.5 to 1.5 mm of space closure per month.

Nordberg[23] investigated the force decay behavior of elastomeric ligature modules. Modules were applied to a model bracket and archwire in a conventional "o" pattern or a "Figure 8." Samples were stored in 37^{oC} water and tested periodically for mean force production over time. A relative wire-to-bracket displacement of 0.5 mm was utilized for force measurements. 2-way ANOVA, correlation coefficient, and linear regressions were used to statistically analyze the data. The following conclusions were drawn. First, a 48% force decay was observed for all samples from 10 minutes to 4 weeks, of which 38% occurred in the first day. Figure 8 application gave a 41% force decay over the same period. Second, statistically, the Figure 8 samples delivered significantly superior force levels than conventionally applied modules, but clinically enhanced tooth movement ability was doubted due to a low magnitude of mean differences. Third, clinical determination of "stiffness" with module application is unreliable in predicting superior force levels over time.

Samuels et. al[24] compared the in vivo rate of space closure of McLaughlin's elastomeric tie back to a nickel-titanium closed coil spring. 17 subjects requiring reciprocal space closure for bicuspid extraction were utilized. All subjects had preadjusted edgewise appliances with .022 by .028 slots, and archwires with .019 x .025 dimensions. The space closure mechanism was randomly assigned to each of the four quadrants in each of the 17 subjects. The Niti closed coil springs were activated to deliver 150 grams of force while the elastomeric module was activated to initial force ranges of 400-450 grams. Space closure was carried out for three patient visits which ranged from 5 to 8 weeks between patient visits (mean of 6 weeks between patient visits) with the maximum duration of 161 days. Linear regression was used to analyze the data. It was noted that the elastomeric module had final forces of nearly zero upon patient return for reactivation. Significance was determined for the independent variables of time and interaction (defined as the spring or elastic module multiplied by time). Insignificance was found for the variables of arch involvement and condition, (defined as type of space closure mechanics). They reported, overall, a greater rate of space closure with the niti closed coil spring. They concluded that a more consistent and greater rate of space closure was possible with the niti spring, and that the lower continuous force may be more biologically acceptable than the intermittent higher forces of the elastomeric module. These conclusions are somewhat unsubstantiated by the results, however. Time and the interaction between time and the spring were found to be significant, not the type of spring. Time seems to be most important, as the time between patient visits ranged from 5 to 8 weeks. Most previous work on elastomeric modules reports activation times of around 4 weeks to maintain proper forces with elastomeric mechanisms.

METHODS AND MATERIALS

Test models as devised by Doyle[16] and Porter[17] were utilized in this project. The 10 models consisted of orthodontic bands for a cuspid, second bicuspid, first molar, and second molar arranged on a plexiglass base to simulate a general arch form with a first bicuspid extraction site. (See photograph 1). The Unitek bands had a standard edgewise twin bracket attached to them and were fixed to the plexiglass material with cold cure acrylic. A .019 x .025" stainless steel archwire was placed in the arch, being ligated with Ormco .120" Power O elastomeric ligatures. To remove the influence of friction on this system, the archwire was cut distal to the cuspid bracket. This allowed free movement of the cuspid bracket during space closure. (See photograph 2). The cuspid bracket was mounted on a separate plexiglass lever which was attached to the plexiglass base by a stainless steel machine screw. Two machine nuts were utilized to prevent the screw from turning while allowing free movement of the lever arm. Within the cold cure acrylic securing the cuspid band to the plexiglass lever a screw eye was placed for the attachment of the force measuring device. (See photograph 3).

A palatal expansion screw was used for simulating tooth movement. The extraction space was initially set between the cuspid and second bicuspid at 5 mm. This width is less than an average initial extraction space based on the average mesiodistal width of premolars in 500 North American caucasian children of 6.9 mm.[25] Five millimeter feeler gauges were used to adjust the initial spaces. (See photograph 4). Subsequent space closure was obtained by 1/2 turns of the expansion screw at the beginning of the second, third, and fourth weeks.

To the approximating surfaces of the cuspid plexiglass lever and expansion screw, 1/4" orthodontic band material was cemented. One inch sections of .025" dead soft stainless steel were welded to one end of each portion of the band material. With contact between the band material, and leads from the dead soft wire to a modified flashlight, a circuit was completed which was signaled by the presence of light. (See photographs 1 and 5).

Unitek gray S2 Posterior Separators, Ormco gray .120" Power O modules and GAC gray .120" Elastoring modules were purchased through product vendors. All materials were stored in darkness at room temperature, in the sealed packaging until used. Randomization was accomplished by cutting the bulk segments into two-unit sections. Ten two-unit sections were randomly selected and then one of the two units were finally selected for use on the test model.

As described by McLaughlin[1] for cuspid retraction, a single stainless steel ligature was passed around the elastomere and then the elastomere was stretched from the second molar hook to a hook on the cuspid bracket. Elastomeric activations were done to approximately two to three times the unstretched dimensions at room temperature. During test runs, all models were stored in a 37^{oC} distilled water bath except during force measurements. Each test module was removed from the water bath for approximately one to two minutes while the force value was being measured, and upon completion, immediately returned to the water bath.

A Chatillon dial push/pull force gauge, model DPP, was used for measuring the force decay. This features ten gram increments with a 1 kilogram upper limit, and a magnetic clutch to hold the maximum force reading. The hook attachment was attached to the screw eye on the cuspid and slowly pulled until the light went out on the flashlight. This signalled a break in contact between the cuspid lever arm and expansion screw for more reliable force recording.

Force measurements were recorded at the time of initial placement, and then subsequently at 24 hours, 1, 2, 3, and 4 weeks. The expansion screw was reduced 1/2 turn after force measures were completed at the 1, 2, and 3 week intervals.

A second group of modules were utilized to test the force decay pattern with an extended time period. Based on the results of the first tests, the Unitek S2 gray separators and the Ormco gray .120" Power O's were selected to test the force decay at 5 and 6 week intervals. Space closure was done at weekly intervals beginning at one week and continued through the 5th week. Force measurements for the second test run were gathered at the 4th, 5th, and 6th week intervals.

For determining the measurement error in recording the force levels, the force measures were duplicated at the two week interval. The first measures were recorded and the models then rearranged to randomize the order for repeating the force measures. The standard error of the measure [$\sqrt{\frac{\Sigma d^2}{2N}}$] was calculated for the difference (d) between the first and second force measurements for each of the ten test models in the first group of test runs.

RESULTS

The force values for each run are shown in Data Tables 1 through 5, reflecting the order the products were tested. Mean force values and standard deviations were calculated for each time interval and appear below each time interval column. Force measurements were replicated at the two-week interval to determine the standard error of the measure for each product in the first test run. Four week space closure, following 1/2 turns of the expansion screw at one, two, and three weeks, was in the order of 1.0 to 1.5 mm.

Mean force levels +/- one standard deviation versus time for the three products are plotted together in figure 1 for the first test run. All three products followed a similar force decay pattern irrespective of the initial force values. The Unitek S2 separators produced the highest initial mean forces and maintained the highest forces for the 4 week test period. The Ormco Power O's produced the lowest mean force levels initially and maintained the lowest force levels for the four week test. The GAC Elastoring elastomere produced force values in-between the Unitek and Ormco units. Initial force values for each product were high, and a sharp decay rate was noted in the first hour with a more gradual rate of decay occurring thereafter. The high initial standard deviations reflect a wide range in initial force production for all three products. With time, however, these values diminished as the force levels within each product test became more uniform.

The repeated force measure at the 2 week interval was dropped from the figures to simplify their reading. The repeated measure was always less than the initial 2 week reading so the first reading was used in all figures and calculations other than the standard error of the measure.

Figure 2 shows the force decay with time as a percent of the initial force. From this the amount of the initial force remaining at any time interval and the rate of decay can be noted. The Unitek separators lost, on average, 33% of the initial force in the first hour, and 43% within the first day. The four weekly intervals showed losses of 43%, 55%, 62%, and 67% respectively. The GAC elastomeres lost, on average, 50% of the initial force in the first hour and 53% within the first day. Respective weekly losses were 56%, 65%, 77%, and 80%. The Ormco Power O's lost, on average, 43% in the first hour and 54% over the first day. Subsequent weekly losses were 58%, 65%, 76%, and 83% respectively.

Statistically, a 2-way ANOVA was utilized to compare the mean force values of the three data sets. Combined with the Scheffe's Multiple Comparisons Test, the effects of the two main variables, (the product and time), could be evaluated. Figure 3. The 2-way ANOVA showed a high degree of significance within the three products and also within the four week time interval (p=.05). Additionally, significance was not shown between the interaction of the products and time. This means the three products acted in a similar fashion over time, which is reflected in figures 1 and 2.

The Scheffe's Test showed the Unitek separators produced statistically significant higher force values than the GAC or Ormco units throughout the four week time interval. (p=.05) The GAC and Ormco force values were statistically indistinguishable at all time intervals and can be considered to produce similar force values. In evaluating within each manufactures product, significant differences were noted between early and late mean force values, but in all three the force levels from 2 weeks through the fourth week were statistically indistinguishable, indicating a relative plateau in the force decay rates.

Force measures were repeated at the two-week interval for determining the standard error of the measure for each test run. The Chatillion force gauge measures in 10 gram increments. The standard error of the measure ranged from 17.8 to 25.6 grams with a mean of 21.6 grams. This error level is higher than desired but adequate given the force levels. The use of a more sensitive force gauge, such as the Instron testing machine is recommended in future studies to reduce the measurement error.

DISCUSSION

The force decay curves for the single elastomeric modules are in close agreement with previous studies for elastomeric C-chains and K-X modules.[2-4,10,11,13-17,23,36] This is expected as the polyurethane material is essentially the same in these studies with only the form being varied. Thus, extrapolation of previous conclusions on C-chain and K-X modules to single elastomeres appears valid.

Typical of these materials, as previously noted, there was a high range of initial force levels and a precipitous drop in these initial force levels in the first 24 hours. In addition to material composition and degradation characteristics being responsible for these findings, the method of activation may also play a role. Rather than a fixed stretch distance which would be expected to produce more uniform forces, activations were done to between two and three times the initial diameter of the modules as indicated by McLaughlin.[1] This was done to better simulate clinical use of the retraction mechanism. As a result, the correlation of initial force to percent elongation could not be determined specifically.

As noted in figure 1, the standard deviations decrease significantly with increased time indicating a decreased range or a conformance of force levels within the individual product test. Also, within each product test, a high initial force level did not relate to a higher four week force level. This is in agreement with previous studies.[21] Because of these factors, the range of force values determined in this study may be more useful than the mean force value reported. Thus, at four weeks, one could expect 95% of the Unitek S2 separators to deliver between 275 grams and 380 grams of force; 95% of the Ormco .120" power O's would deliver between 85 grams and 155 grams of force; and, 95% of the GAC .120" elastomeres would deliver between 50 grams and 280 grams of force.

The effect of simulated tooth movement on the force decay rates for all three products was pronounced. Doyle[16] and Boester and Johnson[9] reported force decay at four weeks of 44% and 60% respectively for fixed stretch distances. Porter[17] reported an 80% reduction with 1 mm simulated movement and 75% reduction with 2 mm simulated movement. In this study the force decay rates for the three products (67% for the Unitek separators and approximately 80% for the GAC and Ormco elastomeres) were in agreement with these previous studies using simulated tooth movement.[9,17,18,36] Figure 2.

The Unitek S2 separators produced significantly more force than the Ormco or GAC elastomeres. This finding was not surprising as the material thickness of the Unitek separator is greater than the other two elastomeres. Similarly, the Ormco and GAC elastomeres are of similar material thickness and were found to have force levels and decay rates which were statistically equivalent.

It has been speculated that space closure could move the system into a zone of permanent deformation for the elastomere which would greatly reduce the force levels. In Samuels et. al[24] comparison of this system versus a niti closed coil spring, it was noted that final forces in vivo were nearly zero for the elastomeric system. The periods between activations ranged from five to eight weeks. In this study permanent deformation of all elastomeres was noted upon their removal at four weeks, but a precipitous drop in force levels to around zero was not seen. As many clinicians choose six week intervals for patient visits, a second group of tests were run to extend the data for fifth and sixth week intervals. These data are seen in Tables 4 and 5. Because there was no statistical difference in force values for the GAC and Ormco elastomeres, only the Ormco .120 Power O's were tested in this second test run. The mean four week force values for the second test runs were close to the mean four week force values for the original data groups:

	1st Run	2nd Run
Unitek	328.0 grams	342.5 grams
Ormco	118.0 grams	132.0 grams

Mean force levels for the Unitek separators remained high through the six week run, (283.8 grams) with only an additional loss of 60 grams from the four week force level. Mean force levels for the Ormco Power O's dropped to 67 grams at six weeks, which was a drop of 65 grams from the four week mean force level. A drop into a zone of permanent deformation was not observed for any material in any test run conducted in this study. Low force values as noted by Samuels, were noted when the time intervals progressed beyond a four week time frame. From these data, the use of the smaller elastomeres may not be advisable for patien visits which will be more than four weeks apart.

There are two central questions which arise from these data First, what effect does friction play in sliding mechanics an second, in light of the frictional component, is the force enoug to give tooth movement over an extended time period.

The role of friction in sliding mechanics has bee extensively researched. Factors involved in this frictiona component have been identified but the influence of these factor remains unclear in some cases. Factors known to increase th friction of the system include the amount of tipping of th bracket relative to the arch wire,[26] (second order position steel versus elastomeric ligation,[31] and surface roughness of th arch wire (TMA versus nitinol versus stainless steel)[29,32] an bracket slot (ceramic versus stainless steel).[27,32] The effec of bracket width and arch wire dimension on the friction leve remains unclear. Early work by Andreasen and Quevedo found negligible influence of bracket width.[26] Others have shown a increased frictional force with increased bracket widths.[28] Stil others have shown decreased frictional forces with increase bracket widths.[30,31] Similarly, several works on arch wir dimension have shown substantial influences on frictiona coefficients[26-30] while a recent paper has suggested th influence to be negligible.[31] Peterson et. al[33] found under th best of circumstances a .019x.025" steel wire in a .022" slo with steel ligatures ties would produce a minimum frictiona resistance to moving a single tooth (i.e. cuspid) along an arc wire to be about 100 grams.[33] Thus, if a 100 gram force i needed for a tooth movement reaction, a total force of 200 gram or roughly twice the needed tooth movement force is required.[35]

From this one would expect frictional resistance to be major factor in tooth movements over an extended time with mechanism which provides decreased amounts of force over time At four weeks time, in this study, only the Unitek S2 separator were delivering force values at a range above this force level The GAC and Ormco elastomeres were both below this force level However, the premise of McLaughlin's retraction mechanism is t lower the frictional component by using a preangulated applianc and attaining proper leveling and aligning prior to th activation of these retraction springs. With these goals met, h feels light continuous forces less than 150 grams will be capabl of elucidating tooth movement by minimizing the tipping action o the tooth. As mentioned previously, tipping will increase the bracket angulation to the arch wire which causes binding and increased frictional coefficients. McLaughlin's theory then is that these light forces will be at levels close to the biologic resistence which must be overcome for tipping to occur. He feels less tipping will allow more bodily retraction of the cuspid with less subsequent taxation to the anchorage unit. Whether or not this holds is beyond the scope of this study. Hixon et. al[36] found that arch wire deflection occurred in their test models in archwires up to .045" with forces above 100 grams.

Individual response to force is also a factor to be considered. Tacy[34] showed a wide range of forces which provided optimum cuspid retraction in individual patients. These forces were at levels below 150 grams as well as up to 800-plus grams. This is in contrast to optimum force levels promoted by research of Storey and Smith.[5]

There are a few clinical implications to the results of this data. In the classical view of space closure and sliding mechanics, retraction forces must be strong enough for the frictional coefficient of the system to be overcome. At what force level this is accomplished is still unclear. Most edgewise proponents probably feel moderate forces in the 150-300 gram range are necessary to realize timely tooth movement. The Unitek S2 separator provides forces over the long term in this force range. Proponents of McLaughlin's technique may want force levels to be less than 150 grams. The Ormco .120" Power O's were best at providing these light forces. However, the length of time between activations must be kept in mind with the Ormco Power O's. The force levels required to move a tooth, even in a friction-less system, were not maintained beyond four or five weeks in this study with the Ormco Power O's.

In terms of a best pick for clinical use of these three products, the Unitek S2 separator appears most versatile. The force range was such that the greatest variability of use could be reached. Lighter forces at 150 grams or less could be attained by a smaller degree of activation of the Unitek separator. This would also probably result in lower mean initial force levels. The converse, increasing the activation of the Ormco or GAC elastomeres to equal those found here for the Unitek separator, would probably give higher terminal mean forces, but also higher initial mean forces. Further study of these alternate activations is necessary to evaluate their efficacy and, in the case of the Ormco or GAC elastomeres, their increased potential for patient discomfort and taxation to the anchorage unit before being advocated.

SUMMARY AND CONCLUSIONS

Three elastomeric products were obtained to test their force decay rates when utilized as a cuspid retraction assembly. McLaughlin promotes light continuous forces in the 150 gram or less range to realize tooth movement using a preangulated .022" appliance with at least one month of prior leveling with a .019x.025" stainless steel arch wire. Ten test models capable of simulated tooth movement were utilized for each product to test the force decay rates of randomly selected samples. All test models were stored at 37^{o}C in distilled water and were removed only for force measuring. Measurements were obtained for initial, 1 hour, 24 hour, 1, 2, 3, and 4 week time intervals. Space closure was on the order of 0.5 mm per week. It was initiated after force measurements were recorded for the 1st, 2nd, and 3rd weekly time intervals. The mean data obtained was analyzed by 2-way ANOVA and Scheffe's tests. A second test run of two of the elastomeric products was conducted to include 4, 5, and 6 week time intervals. Tooth movement was simulated in the second test run at the same time intervals as the first test run and then continued for two more weeks.

The following conclusions were made from the data obtained and analyzed in this study:

1. With similar activation ranges, the Unitek S2 separators provided statistically higher mean force levels at all time intervals than the mean force levels of the other two products through six weeks. The Ormco and GAC .120" elastomeres had mean force levels which were statistically similar to each other.

2. All three products were capable of delivering forces at four weeks which would be below 150 grams. The Unitek S2 separators would need to be activated less than two times their initial diameter, however, to produce these light forces. The exact amount of activation that would be necessary needs to be determined by further study.

3. Force decay rates were similar for the three products tested and were in agreement with previous studies. Four week force reductions were 67% for the Unitek sample, 83% for the GAC sample and 80% for the Ormco sample. The majority of the loss is in the first hour.

4. Subsequent tests of five and six week time intervals showed maintenance of high force levels with the Unitek S2 sample, while force levels with the Ormco .120" sample remained low. The six week mean force level for the Ormco sample was below 100 grams while the Unitek sample was almost 300 grams.

5. High to moderate force levels could be maintained with the Unitek S2 separators for patient recall intervals up to six weeks. Patient recalls beyond four week intervals would likely result in very low force levels with the Ormco .120" elastomeres based on the data presented.

DATA TABLES

Table 1: Ormco .120" Power O's. Raw values for force decay in grams. Average force decay and standard deviation for each time interval given below the individual scores. Two recordings done at two week interval for determining standard error of the estimate.

	t_0	t_{1hr}	t_{24hr}	t_{1wk}	t_{2wk}	t_{2wk}	t_{3wk}	t_{4wk}
Model # 1	630	380	330	200	220	220	160	110
2	430	280	275	170	190	160	190	100
3	725	350	220	200	260	230	130	110
4	729	390	280	290	240	260	170	150
5	410	430	380	360	280	250	150	150
6	790	360	270	310	210	230	120	100
7	650	350	310	310	210	220	150	100
8	655	320	300	260	220	220	160	120
9	1120	590	440	490	280	230	190	120
10	620	420	280	260	270	210	180	120
Mean	675.9	387.0	308.5	285.0	238.0	223.0	160.0	118.0
Stan. Dev.	198.04	84.07	62.36	93.00	32.59	26.69	23.57	18.74

Stan. Error of Measure: 21.56 grams

Table 2: Unitek S2 Posterior Separators. Raw values for force decay in grams. Average force decay and standard deviation for each time interval given below the individual scores. Two recordings given at two week interval for determining standard error of the estimate.

	t_0	t_{1hr}	t_{24hr}	t_{1wk}	t_{2wk}	t_{2wk}	t_{3wk}	t_{4wk}
Model # 1	1090	690	510	500	420	400	350	310
2	950	670	610	530	450	400	360	340
3	930	610	530	550	450	430	350	320
4	900	700	620	640	520	500	420	270
5	910	690	570	630	460	420	400	340
6	920	610	530	550	420	430	380	320
7	950	660	530	570	470	490	420	360
8	980	600	570	550	430	430	330	360
9	1180	720	680	630	450	430	380	310
10	1160	710	570	560	410	420	420	350
Mean	997.0	666.0	572.0	571.0	448.0	435.0	381.0	328.0
Stnd. Dev.	105.83	44.52	52.24	47.01	31.90	33.75	33.15	27.81

Stan. Error of Measure: 17.75 grams

Table 3: GAC .120" Elastomeres. Raw values for force decay in grams. Average force decay and standard deviation for each time interval given below the individual scores. Two recordings done at two week interval for determining standard error of the estimate.

	t_0	t_{1hr}	t_{24hr}	t_{1wk}	t_{2wk}	t_{2wk}	t_{3wk}	t_{4wk}
Model # 1	780	410	380	400	330	310	200	200
2	870	510	500	400	320	280	260	130
3	790	320	260	250	200	220	130	150
4	760	410	490	350	260	240	210	140
5	600	410	410	420	270	320	220	270
6	900	360	330	300	220	220	140	140
7	910	460	430	410	350	290	220	250
8	750	320	300	280	250	240	180	100
9	1070	570	520	510	410	370	180	150
10	830	380	300	320	270	220	190	90
Mean	826.0	415.0	392.0	364.0	288.0	271.0	193.0	162.0
Stan. Dev.	124.11	79.90	92.95	78.49	63.91	51.52	38.60	59.78

Stan. Error of Measure: 25.59 grams

Table 4: Unitek S2 Posterior Separators. Part II. Raw values for force decay in grams for four, five, and six week time periods. Average force decay and standard deviation for each time interval given below the individual scores. (* Due to inconsistent values outside the measurement error, models #1and #5 were deleted from the analysis.)

	t_{4wk}	t_{5wk}	t_{6wk}
Model # 1*	270	340	230
2	290	230	250
3	360	270	250
4	370	340	350
5*	370	450	280
6	330	350	250
7	250	200	170
8	360	340	350
9	330	330	270
10	450	430	380
Mean	342.5	311.3	283.8
Stan. Dev.	59.22	73.96	70.29

Table 5: Ormco .120 Power O's. Part II. Raw values for force decay in grams for four, five, and six week time time periods. Average force decay and standard deviation for each time interval given below the individual scores.

	t_{4wk}	t_{5wk}	t_{6wk}
Model # 1	120	100	50
2	140	90	30
3	150	120	60
4	150	120	60
5	140	160	110
6	150	90	60
7	100	80	70
8	120	80	80
9	130	80	70
10	120	90	70
Mean	132	102	67
Stnd. Dev.	16.87	26.58	20.56

Figure 1

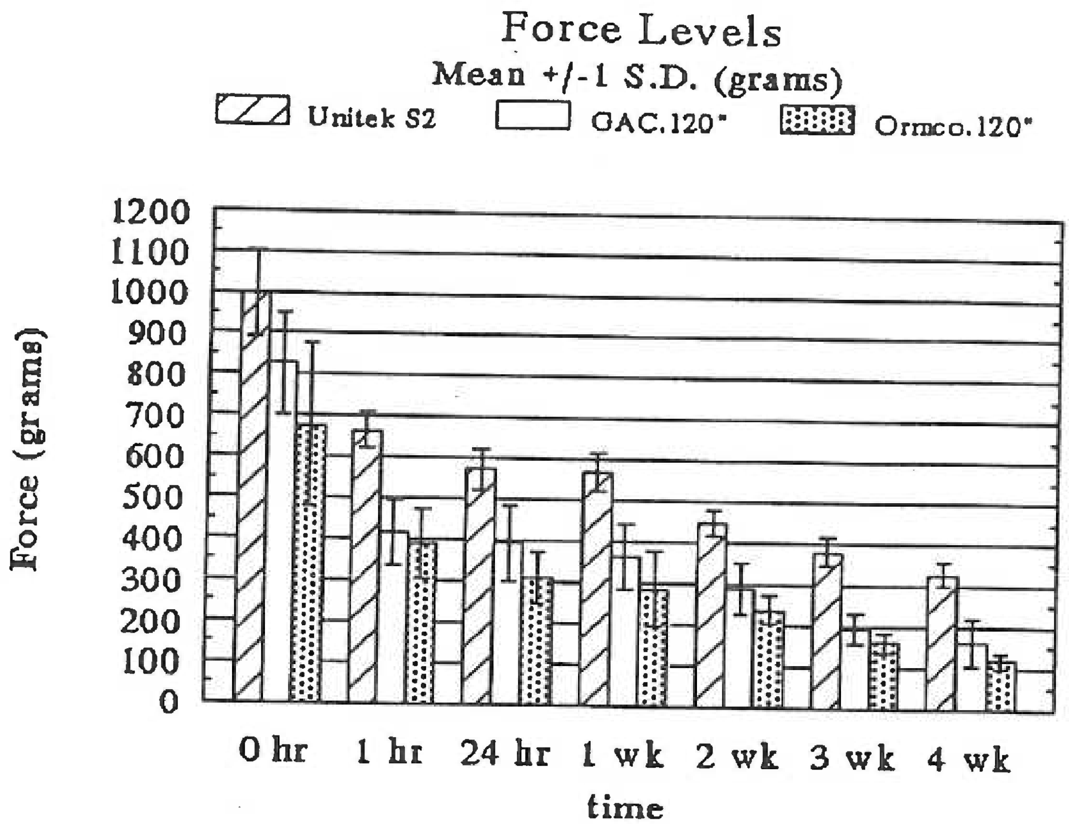
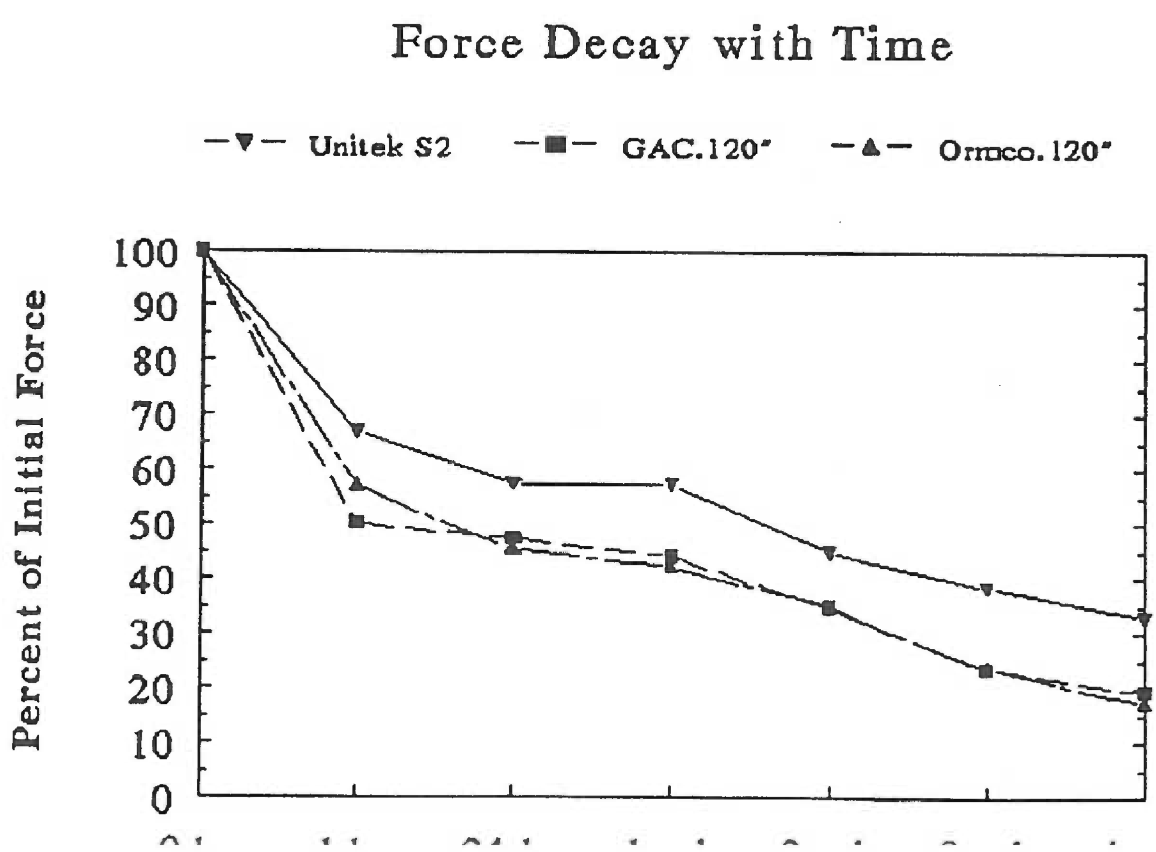
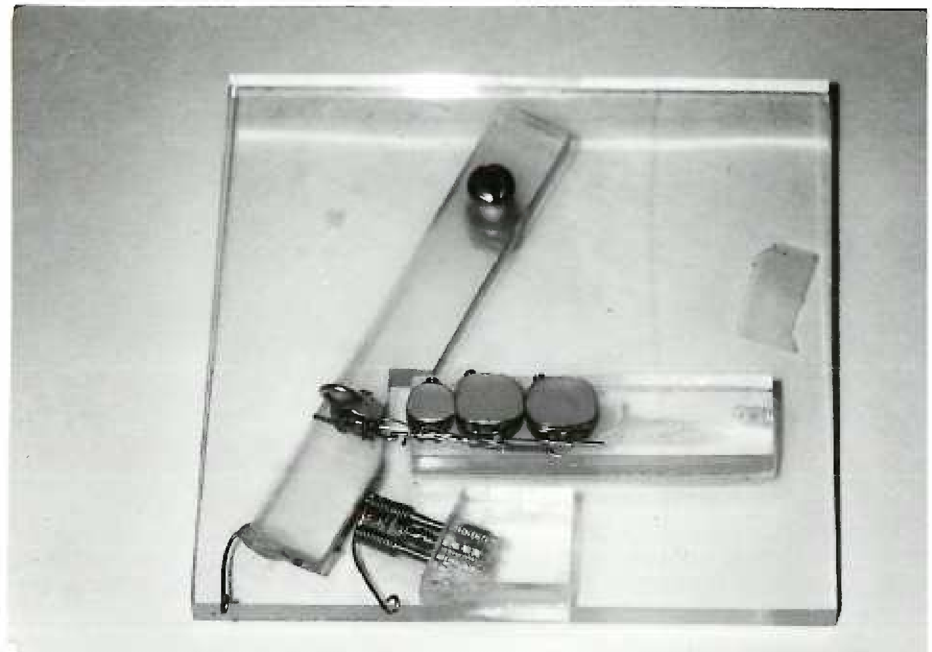


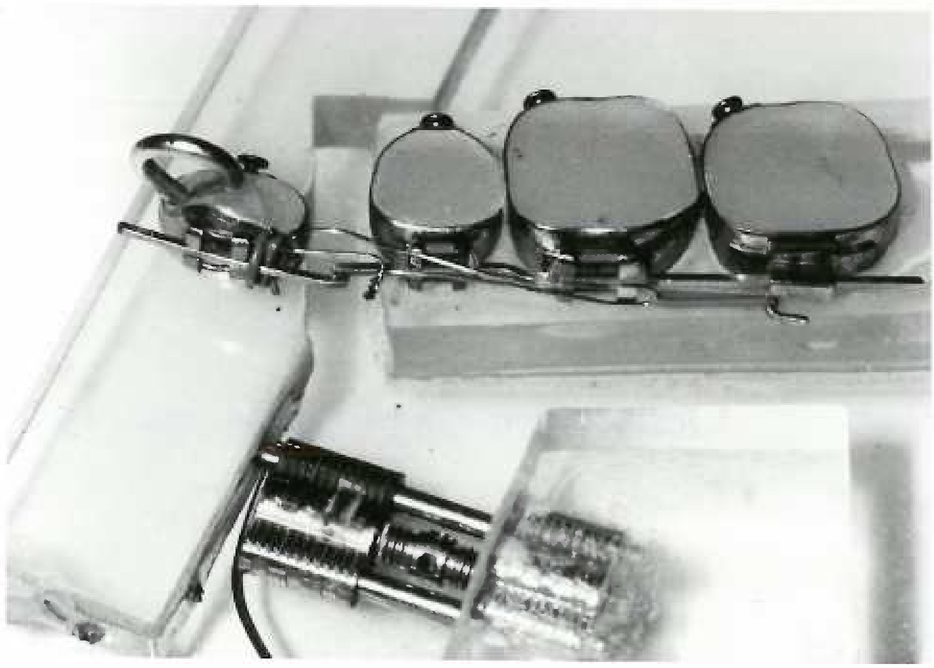
Figure 2



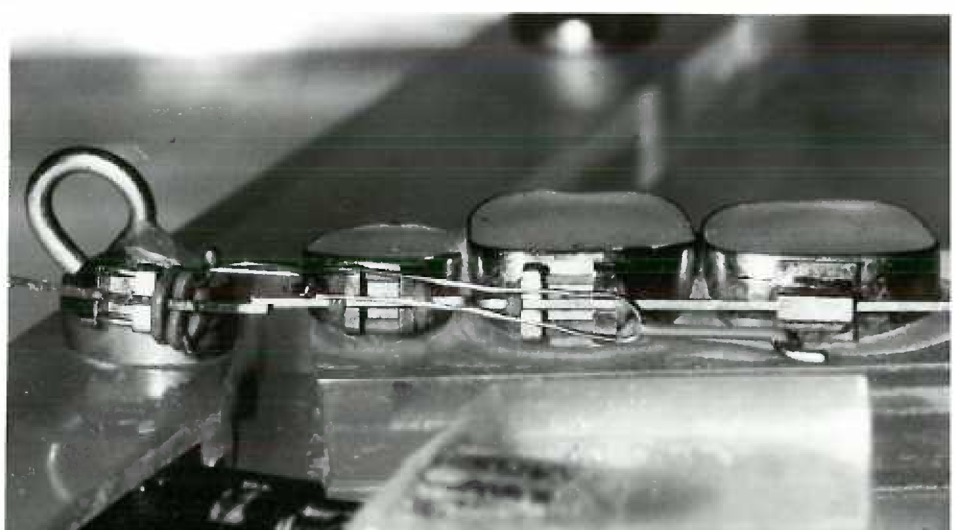
Photograph 1:
Test model



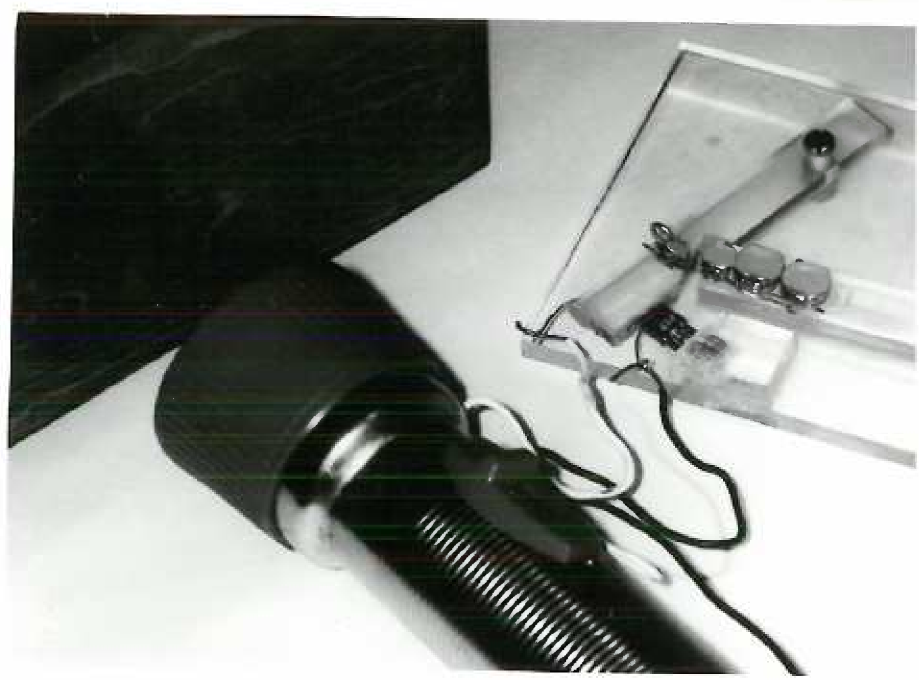
Photograph 2:
Test model



Photograph 3:
Test model



Photograph 4:
Feeler guage



Photograph 5:
Test model
circuit

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INTRODUCTION

Since the introduction of elastomeric materials, their use in space closing mechanics has grown quite popular. Several design variations have been proposed: continuous chains of either open or closed loops ligated to each bracket in the arch, or segmented in each quadrant, or 2, 3, or 4 loop chains stretched from attachments on either side of an extraction site. Research has been quite extensive as to the rate of force decay and environmental influences on these force decay rates for the elastic modules.

The basic goals of space closure mechanics have been to provide a relatively simple mechanism which will generate forces in an adequate range and for sufficient time to translate the teeth across the extraction space. Ideally, the force must be maintained for three to six week intervals depending on the clinicians philosophy of patient visit intervals.

An interesting mechanism of providing space closure has been proposed by Dr. R.P. McLaughlin[1]. In this system a single elastomere of the ligation type is used as the force system. The elastomere is attached to an auxiliary hook and activated by stretching and securing it across the extraction site with a steel ligature. Dr. McLaughlin feels activations of 2 - 3 times the initial length routinely result in 0.5 to 1.5 mm of space closure per four week interval.

The evidence for effectiveness of this system appears to be empirically based and extrapolated from data on elastomeric chain module data. It appears no studies have been published on the nature of the force decay rate for single elastomere modules. The purpose of this study was to evaluate the force decay rate of single elastomere modules when utilized for space closure in the method recommended by Dr. McLaughlin. Three manufacturer's products were tested over a four week time span: Unitek S2 posterior separators, Ormco .120" Power O modules, and GAC .120" Elastoring modules.