# The Influence of Preloading on Stress Relaxation of Orthodontic Elastic Polymers

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The use of synthetic elastic polymers in orthodontics has gained popularity in recent years. They have been used extensively in cuspid retractions, closing diastemas, rotational correction, replacement of ligature ties, and general space closures. Synthetic elastic polymers, however, are imperfect in several respects. They stain permanently shortly after being placed in the oral cavity. Their variability in force delivery is greater compared with latex elastics. They deform 60 percent of their original length as compared with 23 percent for latex elastics. By far the greatest problem associated with elastic polymer lies in the loss of power by approximately 50 percent within the first day. This poses a serious challenge for those who prefer to have a constant, continuous force once it's applied in the oral cavity.

The synthetic elastics are amorphous polymers made from polyurethane materials; however, the exact composition is proprietary information. The polyurethanes are not direct polymers of urethane, but are derived through a process of reactions of either polyethers or polyesters with di- or polyisocyanites to produce a complex structure of urethane linkage. Thus, the major component of a complex polymer is a prepolymer, composed of a linear polyester or polyether that has been extended several times in structural chain length by coupling through urethane linkage.[1]

The polymers are not ideal elastic materials for their mechanical properties are very much dependent on the function of time and temperature. With increase in temperature the polymers become rubbery. The polymers are relatively unaffected by short exposures to water, but decompose under prolonged contact with water, dilute acids or moist heat. These factors also cause swelling and slow hydrolysis.[1] The staining of the elastic polymers in the oral cavity can be attributed to the filling of the voids in the rubber matrix by fluids and bacterial debris.[2] The polymers are degraded by ozone through an autocatalytic process.[3-4] This decreases the tensile strength and flexibility of the elastics. This oxidation process can be protected by the addition of antioxidants like phenyl alpha and betanaphthalamines.

The purpose of this investigation was to determine whether prestretching the polymeric module would decrease the rate of power loss commonly seen with these materials and thereby extend their effectiveness over the typical clinical time period. O'Driscoll[5] maintained that the tensile strength of the polymer could be increased by drawing or prestretching.

## REVIEW OF LITERATURE

Published reports describing the behavior of orthodontic elastic polymers have not been abundant. In addition, the results reported have been difficult to compare because of the variable nature of methods of testing. Since the specific formulations are proprietary, it is very difficult to make comparisons between the various manufacturers' products.

Andreasen and Bishara[6-8] studied the stress relaxation behavior of Alastiks and latex elastics. The Alastiks were found to exhibit the greatest force decay with-

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in the first day. In one series of tests the force decay for the first day was 74.21 percent. In another test K series Alastiks were evaluated and the force decay was found to be 67.5 percent.

Hershey and Reynolds[7] attempted to simulate tooth movement by decreasing the distance of the stainless steel framework on which the modules were attached. At zero rate tooth movement all modules lost approximately 60 percent force after four weeks. In simulated tooth movement there was approximately ⅓ to ¼ of the initial force remaining after four weeks.

Wong[2] found Ormco's Power Chains to be more resilient, more elastic, and less stiff than Unitek's Alastik chains. Under creep test conditions the greatest amount of force decay occurred within the first three hours. The force decay then gradually tapered off and remained relatively constant for the remainder of the experiment.

Kovatch et al.[9] found Unitek's K2 load decay to be more rapid when subjected to a faster extension and higher force load. Consequently, to avoid the undesirable high force decay, they suggested the modules be stretched gradually when being placed in position which they felt might slow down the initial high force decay. However, the effect of this procedure on a long-term basis (3 to 4 weeks) still remains to be proven.

Loyola[10] performed stress relaxation on Alastik chains using the Instron Testing Instrument. His results showed no significant difference between Unitek's CK gray and clear chains. The force remaining after 24 hours was about 50 percent. Using regression analysis, the projected force remaining after three weeks was 33 percent. Unitek's Spool Chains, which apparently are produced by a different process and may even be composed of other chemical components, exhibited a greater load relaxation compared with CK modules.

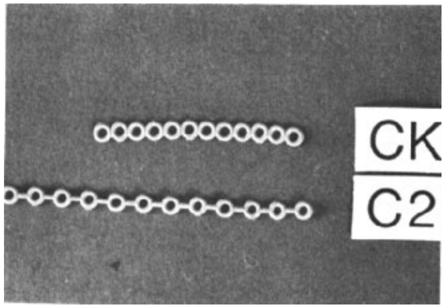


Fig. 1

## Materials and Methods

The Instron Universal Testing Instrument was used for testing the stress relaxation of the Alastiks. This machine has the capacity to stretch the plastic modules to a certain distance, while at the same time recording the stress relaxation of the material. The Instron was selected over the use of gauges for its reliability and accuracy. Newman[3] found the gauges commonly used in orthodontics to be inaccurate after a certain period of use.

Unitek's CK gray and C2 gray Alastiks were used in this investigation (Fig. 1). The modules remained sealed in their plastic containers throughout the experiment until they were randomly selected for testing.

Since the Alastiks are used principally in cuspid retractions, four modules were used for each test sample. Each module represents each tooth from canine to the first molar. An initial load of 90 grams or 0.2 pounds was used for testing the stress relaxation. It was felt that a force approximating 180 grams would be ideal to retract a canine. Alastiks are commonly placed on both the buccal and lingual sides, therefore, a force of 90 grams each side would then give a total force of 180 grams.

A simple sliding apparatus was con-

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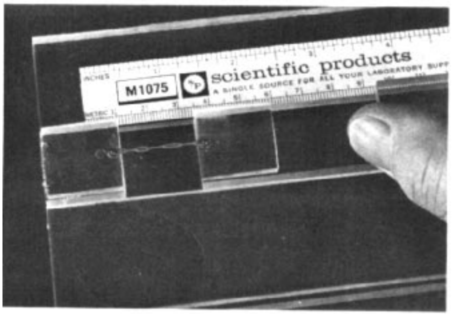


Fig. 2

structed to prestretch the Alastik chain (Fig. 2). Prestretching the chain was done quickly by hand and the chain was returned immediately to its original position. Since there was no previous basis for reference, 14 to 48 mm was arbitrarily selected for prestretching. The specimens were tested in de-ionized water at 37°C + 1.

Five samples were randomly selected for each type of experiment. Both CK and C2 controls were loaded to 90 grams or 0.2 pound for the initial load. In the CK group the modules were stretched to 14 mm (experiment A) and 23 mm (experiment B). For the Alastik C2 group the specimens were stretched to 48 mm (experiment C), 36 mm (experiment D), and 18 mm (experiment E).

A group of Alastik C2 chains was subjected to a higher initial load of 181.4 grams (experiment G). This 100 percent increase in load demonstrated the characteristic behavior of the Alastik under a different stress. Another group of C2 modules (experiment F) subjected to the same initial load as to the control was stored at 100 percent humidity to determine the effect of this environment on the specimens.

## Results

The Alastik CK control at an initial load of 90.7 grams showed an average force of 63.4% remaining after the first hour. Force decay continued to the last measurement, the 24th hour, at which only 43.6% of the initial force remained. The CK sample, prestretched to 23 mm (2.6 pounds), showed an average of 54.8% force remaining after the 24th hour. This was an improvement of 25.7% over the CK control. In experiment B the CK sample, prestretched to 14 mm (1.8 pounds), exhibited a force remaining after the 24th hour of 51%. Again, this was an improvement of 7.4% over the CK control (Table I).

T tests were used to evaluate the statistical significance between the control and the different experimental groups. At 99% confidence limit (T = 3.36), experiments A and B were found to exhibit a statistically significant increase in force over the CK control. At 95% confidence limit (T = 2.31), stretching to 23 mm showed a significantly greater force remaining compared with samples stretched to 18 mm.

The Alastik C2 modules exhibited an entirely different behavior from the CK chain. At the first hour the C2 samples showed an average force of 68.6% remaining. This dropped to 56.4% after the first day. Alastik C2 chains prestretched to 48 mm, 36 mm, and 18 mm exhibited an average force remaining after 24 hours of 52.7%, 57%, and 57.2%, respectively. There was no statistical difference between the C2 control and its various experimental samples.

The average force remaining after the first day for C2 modules exposed to 100% relative humidity was 56.4%. A T test showed no statistically significant difference between this and the control group. As for experiment G, C2 modules subjected to a higher initial load of 181.4 grams exhibited a net force of 48.8% remaining at the 24th hour. At 95% confidence limit there was signifi-

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TABLE I

STATISTICAL RESULTS AND PREDICTIONS

| SAMPLE | STATISTICAL PARAMETERS | | | | | | FORCE PREDICTIONS-WEEKLY* | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | r | $r^2$ | A | B | S.E.E. | F-Value | 1st | 2nd | 3rd | 4th |
| CK Control | -0.97 | 0.95 | 61.51 | -14.3 | 1.17 | 440.03 | 29.6 | 25.3 | 22.85 | 21.0 |
| Experiment A | -0.98 | 0.96 | 66.79 | - 9.2 | 0.68 | 552.56 | 46.1 | 43.3 | 41.8 | 40.6 |
| Experiment B | -0.96 | 0.93 | 67.07 | -11.5 | 1.15 | 299.08 | 41.4 | 38.0 | 35.9 | 34.5 |
| C2 Control | -0.90 | 0.81 | 66.49 | - 9.2 | 1.61 | 98.25 | 45.9 | 43.1 | 41.5 | 40.3 |
| Experiment C | -0.88 | 0.77 | 61.48 | - 8.5 | 1.69 | 76.45 | 42.3 | 39.8 | 38.3 | 37.2 |
| Experiment D | -0.97 | 0.94 | 70.25 | -10.0 | 0.89 | 378.52 | 47.8 | 44.8 | 43.0 | 41.7 |
| Experiment E | -0.94 | 0.89 | 68.06 | -8.9 | 1.13 | 187.71 | 48.0 | 45.3 | 43.7 | 42.6 |
| Experiment F | -0.97 | 0.95 | 71.36 | -11.0 | 0.85 | 495.64 | 46.7 | 43.4 | 41.4 | 40.1 |
| Experiment G | -0.97 | 0.94 | 61.03 | - 9.8 | 0.89 | 361.49 | 39.1 | 36.1 | 34.4 | 33.1 |

r = correlation coefficient
$r^2$=coefficient of determination
A=intercept at Y
B=slope

S.E.E. = Standard Error of Estimate
*Predictions are percentage of force remaining

cantly less force remaining compared with the C2 control group.

A T test was also used to compare the difference between the CK and C2 control groups. At 99% confidence limit C2 control showed a significantly higher force remaining compared with the CK group. Regression analysis was used to predict the amount of force remaining at the end of three to four weeks for all samples tested. The coefficient of correlation (r) for force remaining vs. time was found to be very highly correlated in all of the experimental groups. The statistical results and predictions are listed in Table I.

Finally, tensile failure measurements were made for the CK and C2 Alastik chains containing four modules. The breaking strength for the CK chains was found to be 3.41 lbs. ± 0.29 and 3.33 lbs. ± 0.46 for the C2 group.

## Discussion

The greatest force decay for Alastiks occurred within the first six hours, after which the force decay gradually tapered off. Using semilog regression analysis, it was possible to predict the force remaining in the Alastiks for three and four weeks. It was also found that the force decay as a function of time was highly correlated and that there was a minimum error in the predictions. Consequently, it was possible to study the stress relaxation of the materials for a 24 hour period.

Based on these predictions, it was found the CK control had 21% of the original force remaining after the fourth week, while the C2 control had 40% remaining. The force decay between the first and fourth week was not greater than 9% of the original force in any group of the Alastiks tested. In fact, the difference in force between the third and fourth week was no greater than 2%.

Rapidly prestretching and returning the CK Alastik chain to a selected distance significantly increased the amount of force remaining after 24 hours to 17-25%. However, the force remaining after four weeks was 64-93% greater than the control. Chains prestretched to 23 mm were found to be significantly

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more effective than those stretched to 14 mm.

Unlike the CK Alastiks, the C2 group was not affected by prestretching. The difference between the behavior of these two materials may be due to the difference in shape and/or polymer composition.

The effect of a 100% increase in initial force (180 grams) on C2 Alastik resulted in significantly greater force decay than the control. It appears that at these force levels the material has been plastically deformed. This is in contrast to Loyola,[10] and Hershey and Reynolds[7] who felt that a difference in initial load would have no effect on the degree of stress relaxation. This, in fact, may be correct assuming the initial load does not exceed the elastic limit.

In addition, Andreasen and Bishara[6] suggested stretching Alastik chains three to four times the intended load to compensate for subsequent force decay. At these initial force levels it is likely that the elastic limit will be exceeded and actually decrease the effective force remaining at three or four weeks. Also at these high initial loads the problem of undermining resorption due to capillary damage cannot be ignored.

Storage of Alastik chains in a high humidity environment did not significantly affect the strength or stress relaxation of these materials. This phase of the investigation was suggested by the well-known fact that polyurethane polymers undergo slow degrading change in the presence of moisture.[1]

Both of the Alastik chains are fabricated with 12 modules with the CK type having three injection sites and the C2 with four. In the CK chain the module farthest from the injection site suffered the greatest distortion in tension. With regard to the C2 chain the intermodular links suffer the greatest distortion. It was felt that those distorted areas suffered the greatest amount of stress relaxation.

## Conclusion

The main objective of the investigation was the determination of whether prestretching would decrease the rapid force loss of the elastic polymers. The results indicated that Alastik CK chains showed a significant decrease in force loss whereas the C2 chains were unaffected. Since overextending the chain to compensate for force loss during clinical placement could result in capillary bed ischemia, increasing the force loss of the CK chains must be done before application. To accomplish this the chains should be prestretched by the manufacturer or operator. An improvement in the material component or manufacturing process would provide a more lasting solution to a material for which orthodontists have found increasing use.

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