Original Article

Evaluation of Force Degradation Characteristics of Orthodontic Latex Elastics in Vitro and In Vivo

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ABSTRACT

Objective: To evaluate the characteristics of force degradation of latex elastics in clinical applications and in vitro studies.

Materials and Methods: Samples of 3/16-inch latex elastics were investigated, and 12 students between the ages of 12 and 15 years were selected for the intermaxillary and intramaxillary tractions. The elastics in the control groups were set in artificial saliva and dry room conditions and were stretched 20 mm. The repeated-measure two-way analysis of variance and nonlinear regression analysis were used to identify statistical significance.

Results: Overall, there were statistically significant differences between the different methods and observation intervals. At 24- and 48-hour time intervals, the force decreased during in vivo testing and in artificial saliva ($P < .001$), whereas there were no significant differences in dry room conditions ($P > .05$). In intermaxillary traction the percentage of initial force remaining after 48 hours was 61%. In intramaxillary traction and in artificial saliva the percentage of initial force remaining was 71%, and in room conditions 86% of initial force remained. Force degradation of latex elastics was different according to their environmental conditions. There was significantly more force degradation in intermaxillary traction than in intramaxillary traction. The dry room condition caused the least force loss.

Conclusions: There were some differences among groups in the different times to start wearing elastics in intermaxillary traction but no significant differences in intramaxillary traction.

KEY WORDS: Latex elastics; Force degradation; Clinical application

INTRODUCTION

As a generally auxiliary method, latex elastics are characterized by high flexibility, relatively enduring force, and low cost. It is easy for patients to change the elastics by themselves and maintain good oral hygiene. Elastics made from natural rubber were first introduced by Baker and have been applied up to the present.

Natural rubber is a kind of elastomer that forms a three-dimensional reticulate structure by cross-links. Its elastic properties depend on irregular twisted arrangements of long molecular chains linked together at certain points by covalent bonds between different atoms such as sulphur with two carbon atoms.[1] When latex elastic loads a certain force beyond its stress limit, fatigue begins at the weak points brought by its inside or surface lack of homogeneity. Simultaneously, friction between the molecular chains also causes dynamic fatigue.[2] The physical and chemical properties of latex cause orthodontic elastics to undergo fatigue, and force relaxation results in force degradation that is likely to be accentuated under adverse environmental conditions, such as in the oral cavity.[3]

Force-extension characteristics and force decay properties of latex elastics have been reported for

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Accepted: August 2006. Submitted: February 2006.

many years.[4–7] It has been a common finding that rubber elastics will lose a part of their initial force after they are applied in the mouth for the purpose of oral activities (eg, chewing, speaking) and after they are exposed to different environments (eg, saliva, oral temperature, foods and drinks with different acidity and alkalinity). All these procedures (ie, repeated stretching and different environments) could change the structure of latex elastics and affect their properties. Some in vitro studies have been designed to simulate kinds of saliva, thermocycling, and even the daily diet in order to study the changes of elastics.[3,8] Elastics experience constant force expression with considerable force degradation through the first day of use. Most of the degradation is in the first hour.[1,9,10]

However, situations in real oral cavity conditions are much more complicated. Patients frequently undergo various oral activities in the daytime that can be regarded as a dynamic environment for the elastics. It was proposed that the normal range of clinical use during talking and chewing is between 20 and 50 mm.[11] Although there are few oral activities during sleep, the length of stretched elastic is almost the distance between two traction hooks. This is a relatively static environment. Most studies have examined force delivery in the static environment, though a few studies have looked at the effects of dynamic testing.[11,12] The results show that cyclic testing (repeated stretching) causes significantly more force loss than static testing and that this difference occurs primarily in the early period. Liu et al[11] also found that the deterioration did not increase directly with the amount of restretching and that the effect was not statistically different beyond 200 cycles.

The experimental data undoubtedly remind us to consider whether there are differences between force changes of latex elastics in clinical application and in vitro tests. Can the elastics provide the expected force when influenced by so many factors, and how should they be used to efficiently meet the treatment needs?

This study was designed and implemented to evaluate the characteristics of force degradation when the testing was conducted in vivo and in vitro over a 48-hour period and the elastics were exchanged at different times in oral cavities. We have attempted to collect experimental information that will provide guidelines for clinical application.

MATERIALS AND METHODS

The samples of orthodontic latex elastics (3M Unitek Corporation, Monrovia, CA) were investigated at a 3/16-inch size. They were within their expiration dates and stored in sealed plastic packages in a cool and dark environment.

Twelve students (12–15 years of age) in a boarding school and who wore fixed appliances were selected for the study. This study was approved by the Ethics Committee of Wuhan University Hospital and School of Stomatology, and informed consents were obtained. The subjects were required to participate in the experiments four times and were formed into four groups (A, B, C, and D). Elastics were stretched 20 mm, representing intermaxillary traction in groups A and B and intramaxillary traction in groups C and D.

In groups A and B, Class II or III intermaxillary tractions were applied according to the subjects' treatment. Elastics were placed on both sides of every subject, and all force magnitudes were recorded, but only those on one side were included in the statistical analysis. When the elastic broke or obvious flaws were seen in the elastic, the other side was substituted. Subjects in group A started to wear elastics at 0700 hours (before breakfast), whereas subjects in group B started to wear elastics at 2100 hours (before sleeping) and were required not to do more oral activities after wearing them. Group C had the same starting time as group A, and group D had the same starting time as group B.

Before the tests, the position and the distance of stretching were determined and the traction hooks were placed on the brackets. The distance of intermaxillary traction between the two hooks was determined while the subjects were in dental interdigitation. The subjects were required to wear the elastics for 48 hours without exchanging them. Force measurements were made at 11 intervals: 0.5, 1, 2, 3, 6, 9, 12, 18, 24, 36, and 48 hours.

With a pair of tweezers, each elastic band was carefully transferred to the ergometer from the subjects mouths in the sequence of intervals. Force magnitudes of the elastics when stretched at the distance of 20 mm along the scale were recorded immediately after they were removed from the mouths. The tensile readings were recorded in newtons. To ensure the consistency of the tests, all measurements were performed by one person, (Dr. Wang).

The subjects were students in the boarding school who dined, slept, and went to class according to the school's schedule. The food consumed is listed in Table 1. Every subject was told to avoid eating food with rough edges so as to prevent breakage of the elastic bands.

In contrast, groups E and F were set in two kinds of artificial conditions. Elastics were mounted between stainless steel pins on an acrylic board at the same 20-mm distance (Figure 1). The board for group E was stored in artificial saliva maintained at 37°C throughout the test. The other board for group F was placed in dry room condition. The observing time and measuring methods were identical.

Table 1. Food list during the testing period

Mealtime	Food
Breakfast (0700 hours)	Steamed bread, boiled egg, congee
Meal in the midmorning (1000 hours)	Biscuits and milk or mineral water
Lunch (1200 hours)	Rice, cooked vegetables, meat, bean curd, soup
Supper (1730 hours)	Rice, cooked vegetables, meat, soup
Food taken late at night (2030 hours)	Bread or cake, sweet soup

An ergometer with load cell capacity of 2 N (Suihua Gaoke Electronics Co Ltd, China) was used. The maximum permissible tolerance was ±0.05 N and the accuracy grade was 2.5 (from the manual specification). The ingredients of the artificial saliva were as follows: 1.3 g/L potassium chloride, 0.1 g/L sodium chloride, 0.05 g/L magnesium chloride, 0.1 g/L calcium chloride, 2.5×10^{-5} g/L sodium fluoride, 0.035 g/L potassium dihydrogen phosphite (KH_2PO_4), and 0.162 g/L $ZnSO_4$. The pH value was 7.0.

For each group and interval, the means and standard deviations were calculated. Repeated-measures two-way analysis of variance (ANOVA) was used to determine statistically significant differences among various testing methods and different times. The Tukey-Kramer honestly significant difference (HSD) test was used to identify statistically different groups when ANOVA indicated a statistical difference. Comparisons were also made between the loads maintained in different groups at 24- and 48-hour intervals. Additionally, a nonlinear regression analysis was used to assess the environmental effect on force decay for each group. The chosen level of confidence for all statistical calculations was .05.

RESULTS

In groups A and B, four elastics broke early or late in the second day, and flaws with different degrees were found on the edges of seven elastics among the total number (n = 48). However, all the elastics in groups C, D, E, and F survived the entire testing without obvious damage. The initial forces in six groups were compared, and there were no statistical significant differences ($P > .05$).

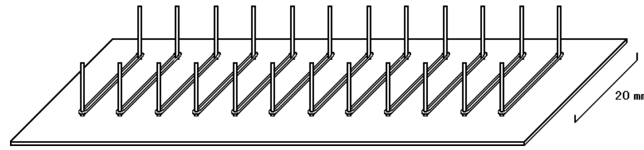

Figure 1. Acrylic board on which the distance between two rows of stainless steel pins was 20 mm.

The changes of means and standard deviations of the force magnitude in the different groups are shown in Table 2. The standard deviations were tested conforming to the Center Ultimate Theorem, showing that the means of the force magnitudes were representative. Overall, there were statistically significant differences among different testing methods and different observation intervals. The Tukey-Kramer HSD test was used among different groups and times. The further analysis showed that each comparison between any two groups indicated significant differences ($P <$ .05) except between groups C and D. At 24- and 48-hour intervals, the force magnitude significantly decreased in groups A, B, C, D, and E ($P < .001$), whereas there was no significant difference in group F at the same two intervals ($P > .05$).

Figure 2 shows the changes in percentage of the initial force during the 48 hours in six groups. All groups showed force decay over time, with the greatest force loss in the first half hour. The percentage of initial force remaining after 48 hours was around 61% in groups A and B and around 71% in groups C, D, and E. However, the percentage of initial force in group F remained at a relatively high level (86%).

The nonlinear regression analysis (exponential de-

Table 2. Grouped data for means (standard deviations) of force over time

	Group					
Time, h	A	B	C	D	E	F
0	1.42 (0.06)	1.42 (0.08)	1.41 (0.06)	1.42 (0.07)	1.42 (0.07)	1.41 (0.05)
0.5	1.14 (0.06)	1.19 (0.07)	1.21 (0.06)	1.22 (0.07)	1.23 (0.07)	1.32 (0.06)
1	1.08 (0.07)	1.13 (0.07)	1.14 (0.05)	1.15 (0.07)	1.18 (0.05)	1.27 (0.07)
2	1.07 (0.06)	1.10 (0.07)	1.11 (0.05)	1.12 (0.08)	1.15 (0.07)	1.24 (0.07)
3	1.06 (0.06)	1.09 (0.07)	1.09 (0.06)	1.10 (0.07)	1.13 (0.06)	1.24 (0.07)
6	1.03 (0.06)	1.07 (0.07)	1.08 (0.05)	1.09 (0.07)	1.11 (0.07)	1.23 (0.07)
9	1.01 (0.06)	1.06 (0.06)	1.07 (0.05)	1.08 (0.07)	1.10 (0.07)	1.23 (0.07)
12	0.99 (0.06)	1.00 (0.06)	1.06 (0.05)	1.06 (0.07)	1.09 (0.07)	1.23 (0.07)
18	0.97 (0.05)	0.95 (0.07)	1.05 (0.04)	1.05 (0.06)	1.07 (0.07)	1.22 (0.07)
24	0.96 (0.05)	0.92 (0.06)	1.04 (0.04)	1.03 (0.06)	1.06 (0.06)	1.22 (0.07)
36	0.91 (0.06)	0.90 (0.06)	1.02 (0.05)	1.01 (0.06)	1.04 (0.07)	1.22 (0.06)
48	0.88 (0.07)	0.87 (0.06)	1.00 (0.04)	1.00 (0.06)	1.02 (0.07)	1.21 (0.06)

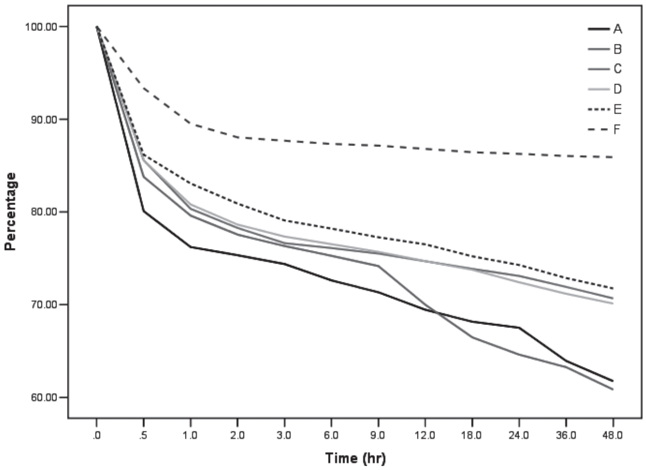

Figure 2. Line graph of force decay over time for elastics.

cay) of the force curves was used for different methods. The results showed that the degree of curves fitting in all groups was good except in group F. Comparing the modes of the force decay curves, groups C, D, and E were similar, whereas group A was close to group B.

DISCUSSION

Different environments have different effects on the properties of orthodontic latex elastics, especially because the oral environment has the potential to plasticize such polymers. In previous reports where the majority of the studies were in vitro studies, the experimental conditions could be controlled accurately and the results were also reproducible. However, in the oral cavity, the characteristics of elastics are affected by many routine factors such as oral activities, oral liquid environment, different foods, and some other indefinite factors. Therefore, simple in vitro testing is unable to represent the actual clinical applications. In this study, many more variables, such as extensions, pH, and thermocycling, have been taken into account.

Similar to what was displayed in previous studies,[3,9,12] the most significant elastic force decrease occurred in the first half hour, both in vivo and in vitro. As time progressed, the degradation became slower. There is a relatively much smaller loss with continued stretching for longer periods.[3,10,13,14] In artificial saliva (37°C) and conditions at 300% extension lengths, Hwang and Cha[15] showed that after 1 day the force decay was about 23% to 28%. The results of group E in our study agree with this finding.

In dry air conditions, group F showed a force decrease to 88% of the initial force at a 2-hour interval. After that the curve slope from 2 to 48 hours decreased slightly, remaining at 86% in the end. There were no significant differences between the 24-hour interval and the 48-hour interval. The trend of drop-off was similar to what was observed in earlier studies.[3,4,11] However, when the elastics were immersed in water at 37°C as in the study by Kanchana and Godfrey,[3] the trend was different. The force decreases were more distinct in groups A, B, C, and D with elastics worn in subjects' mouths and were more distinct in group E with elastics in artificial saliva of 37°C than in F group. At a 24-hour interval, the force decreased to 65% to 73% in the subjects' mouths, and the force losses were more in the intermaxillary traction than in the intramaxillary traction. In these groups, there were significant differences between the 24- and 48-hour intervals.

In clinical practice, patients are usually required to discard the elastics after 1 day of use. The results of this study indicate that, after the elastics have been used for 1 day, the further force reduction was relatively small, averaging 4% to 6% in intramaxillary traction and 2% in intermaxillary traction over the second day. Liu et al[11] confirmed the force decay was remarkably stable because the structural changes caused by repeated stretching were not cumulative. Some studies suggest that the elastics do not need to be replaced so frequently because after the extreme rate of force decay in the first day the force could remain relatively constant for a few days.[10] However, after the clinical observation for 48 hours in these studies, the appearance of all elastics in groups C and D kept well. However, fractures and flaws occurred in groups A and B. Therefore, individuals should change the elastics every day when intramaxillary traction is required and, if necessary, check the edges of elastics carefully to ensure enough force.

According to the findings of force loss, the clinician is suggested to choose between an initial force much higher than desired and a force near the desired amount that will quickly decay to below the level required for the desired effect.[12] It is not only important for the practitioners to know the properties of elastics well, but necessary for the manufacturers to show the properties of force degradation of their products because of the difference for different brands of elastics.[8] It would also be useful to stretch the elastic bands in advance between two hooks on a custom-made board for 1 or more hours before wearing to avoid the extra force delivery in the initial period.

In the results of nonlinear regression analysis, groups C, D, and E showed that the ways of force decay in these three environments are similar. In the oral cavity, the elastics undertook the effects of different foods and liquids and were not affected any more than the elastics in group E (fixed extension and constant temperature of 37°C). However, the trend of the force decay in groups A and B were different because the force is a dynamic extension when accompanied by oral activities. Restretching in an oral environment caused more fatigue, creep, and force relaxation, and, with the increase of the temperature, the fatigue longevity of natural rubber decreases.[16] The curve of force decay in group F was special, in which the influential factors were just static extension and the relatively lower room temperature.

Latex elastics are polymeric elastomers; therefore, viscoelastic properties are of major importance. The viscoelasticity of time-, load-, and temperature-dependent behavior characterized by changes in polymer chain conformation during tensile loading[17] is exhibited. The phenomenon of swelling can also be used to interpret it.[18] Because of the chemically cross-linked points between the molecular chains, latex rubber absorbs liquid molecules into its three-dimensional reticulate structure. With the simultaneous effect of mixing entropy, the free energy of latex rubber decreases. At the same time, the molecular chains are elongated, accompanied by the decrease of elasticity of latex rubber. It has been proven that the degree of swelling of solvent to latex rubber is higher in extension than in relaxation. Thus, the elasticity and force degradation are different in various environments (intermaxillary extension, intramaxillary extension, artificial saliva, and dry air condition).

In the starting period, the force degradation in group A was more obvious than in group B. Elastics in group A first underwent the dynamic environment in which factors such as frequent oral activities, saliva, foods, temperature, and acidity and alkalinity affect the properties of latex elastics. However, elastics in group B first underwent the static environment with less influential factors including saliva, relatively stable oral temperature, and occasional oral activities. When elastics in group B underwent the dynamic condition in daytime, they showed a relatively higher force value than group A. But the force decay in groups C and D were similar in every corresponding period, showing that the time of exchange did not work on force decay in intermaxillary traction.

Although in a static environment, the results in groups C, D, E, and F were not completely in accord. In the similar oral cavities, the force decay in groups C and D were less in their counterpart period compared with groups A and B. The phenomenon illustrated that although mechanical stretching caused by the oral activities was a primary effect, it was one among all the influential factors[3,19,20] such as oral temperature, salivary situation, enzymes, and acidic and alkaline stimuli caused by various kinds of food.

CONCLUSIONS

a. Various environments affected the force degradation of orthodontic elastics. The force decay was more obvious in intermaxillary tractions than in intramaxillary tractions. The situation of dry air condition caused the least force loss.
b. The most significant force degradation occurred in first half hour, during both in vivo and in vitro studies. But the magnitudes of force loss were different.
c. When elastics were applied in intermaxillary tractions, there was some difference among groups at different times to start wearing elastics, whereas there was no significant difference in intramaxillary tractions.

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