Original Article

Orthodontic Latex Elastics:
A Force Relaxation Study

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Abstract: The objectives of this study were to assess the force relaxation of latex elastics occurring within 24 hours of extension and to estimate the extension required to reach the reported force. Five specimens of various manufacturers' latex elastics size and force levels were mounted on a custom-made setup capable of monitoring force levels in real time with a continuous mode and without operator intervention. The percentage of force relaxation was estimated from the initial and 24-hour levels, and the results were analyzed with one-way analysis of variance and the Tukey test at $\alpha = 0.05$ level of significance. The elastics showed force relaxation in the order of 25%, which consisted of an initial high slope component and a latent part of decreased rate. Most relaxation occurred within the first 3–5 hours after extension, regardless of size, manufacturer, or force level of the elastic. The overall as well as the initial relaxation curves were fitted to equations, which described the variation of force with time. Elastic extension to achieve the reported force was found to range between 2.7 and five times the original length. Latex elastics show force relaxation in the order of 25%, which consists of an initial high slope component and a latent part of decreased rate. Most relaxation occurs within the first 3–5 hours after extension, regardless of size, manufacturer, or force level of the elastic. The empirical rule of ''3'' shows remarkable variation, ranging from 2.7 to five. (*Angle Orthod* 2006;76:475–479.)

Key Words: Orthodontic; Latex; Elastics; Force; Relaxation; Extension

INTRODUCTION

Mechanotherapy in orthodontics often involves the use of interarch latex elastics to correct sagittal discrepancies or vertical elastics to improve the interdigitation of teeth. Whereas these auxiliaries are replaced on a daily basis, a concern associated with their use pertains to the force relaxation of the materials.

In the relevant literature, most efforts have focused on assessing the force-time characteristics of chains mainly because these are expected to function in the oral cavity for longer periods, which may exceed 3 weeks. However, studies on this issue have shown a high force decay rate, which consists of two slopes: an initial rapid force relaxation and a latent decay of a decreased slope. The initial high-slope decay rate occurs within 3–4 hours after extension of the material, whereas the less steep curve follows for the rest of the examination period.[1–7] Therefore, it is possible that the relaxation of latex elastics follows the same pattern, and thus, the daily renewal of these auxiliaries may not prevent a force-decay phenomena.

Apart from the potential importance of relaxation of elastics, a question exists regarding the required extension of elastics to achieve the force reported by the manufacturer. At present, there is an empirical rule (rule of ''3''), which indicates that the elastics exert the reported force at an extension of 300% of their diameter. Nonetheless, the validity of this proposal has been seriously questioned and the force levels may vary with the size and force level of the elastics.[7–9]

The hypothesis tested in this study was that the relaxation of elastics as well as the extension required to produce the force reported by the manufacturer are material dependent. Therefore, the purpose of this study was to assess the force relaxation of latex elas-

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TABLE 1. The Latex Elastics Included in the Study

Code	Size(diameter) Inches (mm)	Force oz (g)	Manufacturer
I	3/16 (4.8)	4.5 (128)	Ortho Technology, Fla
II	3/16 (4.8)	6.5 (184)	Ortho Technology, Fla
III	1/4 (6.4)	3.5 (99)	Glenroe, Fla
IV	1/4 (6.4)	4.5 (128)	Ortho Technology, Fla
V	5/16 (7.9)	6 (170)	ORMCO, Glendora, Calif
VI	3/8 (9.5)	3.5 (99)	Glenroe, Fla
VII	3/8 (9.5)	4.5 (128)	Glenroe, Fla

tics occurring within 24 hours of extension and to estimate the extension required to reach the reported force.

MATERIALS AND METHODS

The latex elastics included in the study are shown in Table 1. The initial inner diameter of five specimens of each group was measured with a digital caliper (Mitutoyo, Tokyo, Japan). For this purpose, the elastic's initial inner diameter was taken as reference, and the distance was measured in millimeters. Each specimen was extended to the level that the elastic exerted the force reported by the manufacturer with an accuracy of 1 g.

To assess the relaxation of elastics, a portable test assembly was developed to monitor the force exerted from an extended elastic during the testing period, in real time and with a continuous data collection mode (Figure 1). The main components of this assembly were a 2-kg load cell (RS components 632-736, RDP Electronics, Wolverhampton, UK) connected with a strain gauge and an amplifier (RS components 846-171), a power source unit and a machine vice. On extension of the elastic, by opening the vice jaw, there is a change in the voltage, which is magnified by the amplifier and sensed by the strain gauge unit of the assembly. The assembly was connected to a signal-conditioning unit (E307-3 RDP Electronics), linked to a computer with a data logging software (Picolog technology systems, Cambridgeshire, UK) via an ADC-16 (Analog to Digital Converter) multichannel data acquisition unit.

Recording of force for the entire period of study was performed in real time, without any operator interferences and under a continuous mode, at 15-second intervals. Because the method of recording involves millivolt units possessing a negative sign, the data should be transformed to gain physical meaning, and this is achieved by multiplying them by −1. The calibration of force unit (grams) with millivolt units was performed by extending a specimen to increasing lengths to produce various loads in the order of magnitude exhibited by the elastics tested. These loads were measured with a dynamometer, and the selection of grams as opposed to Newton units was based on the familiarity of clinicians with this units.

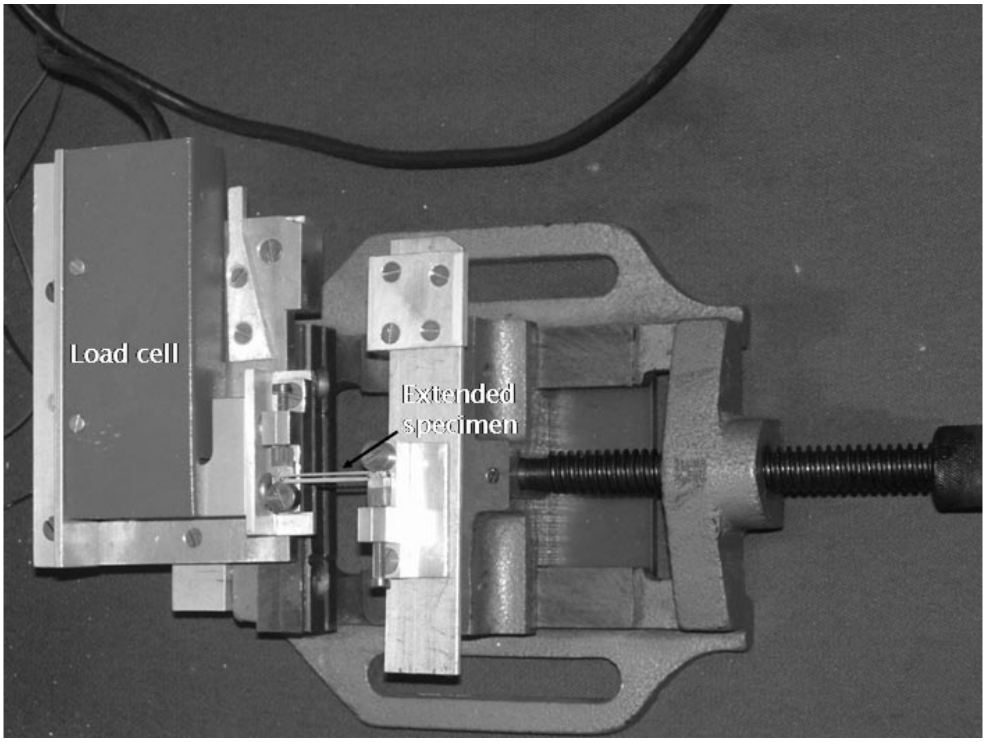

FIGURE 1. The testing assembly used for the study of force relaxation of elastics.

TABLE 2. Force Relaxation at 24 Hours of Latex Elastics and Extension Required to Achieve Reported Force

Code	Extension to Achieve Reported Force × Diameter	% Force Relaxation at 24 Hours		Tukey Grouping[a] for Relaxation
		Mean	(SD)	
I	2.7	25.4	(3.20)	
II	2.7	23.02	(1.62)	A
III	3.0	27.49	(0.95)	A
IV	3.0	24.08	(1.90)	A
V	5.0	28.70	(2.03)	A
VI	2.6	29.26	(7.25)	A
VII	3.0	22.74	(0.54)	A

[a] For force relaxation data, means with same letters are not significantly different at the $\alpha = 0.05$ level.

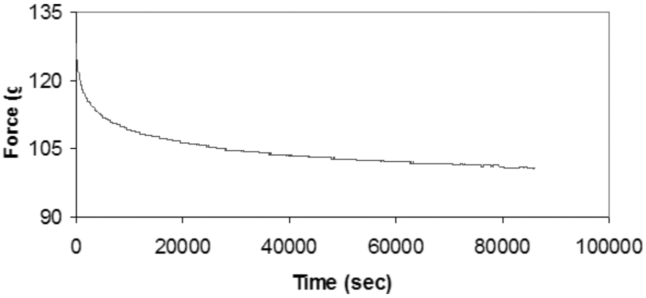

FIGURE 2. Representative force relaxation curve for a 3/16-inch, 4.5-oz latex elastic specimen.

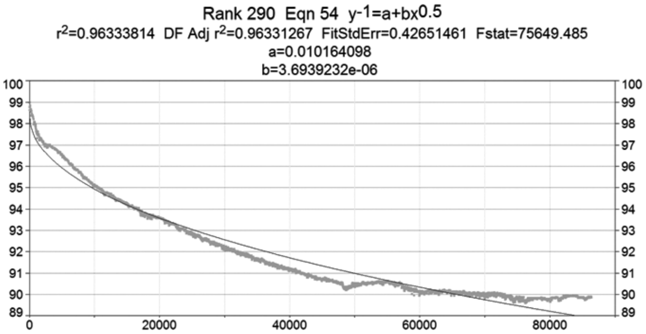

FIGURE 3. Representative relaxation curve fitting for the entire period of study (24 hours) of a latex elastic.

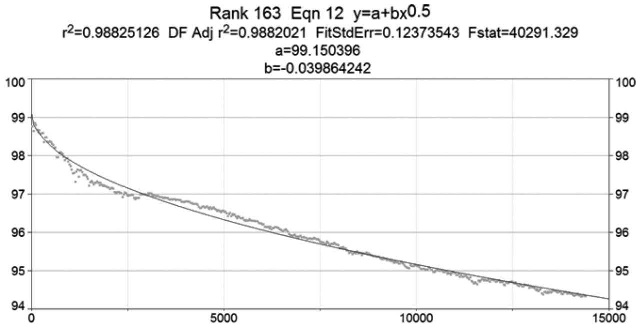

FIGURE 4. Relaxation curve fitting for the initial steep component (4 hours).

From each specimen, the percentage of force relaxation (%R) was obtained as follows

$$\%R = 100 \times \frac{Fo - Ft}{Fo}$$

where

Fo: initial force (reported by the manufacturer)

Ft: force at 24 hours.

Relaxation curve fitting was performed with the relevant software (TableCurve 2-D, SPPS, Chicago, Ill). The relaxation of the five specimens of each group was averaged, and the results were analyzed with one-way analysis of variance. Further group differences were investigated with the Tukey's multiple comparisons test at $\alpha = 0.05$ level of significance.

RESULTS

Table 2 (second column) shows the extension recorded, under which the reported force was achieved. Although most of the elastics show a value of 2.7–3.0, in two cases this ratio was found to be as high as five.

In Figure 2, a representative force-time curve of elastic is demonstrated, where it is evident that the curve could be separated in two distinct components: a high initial rate and a lower slope part. The first, which represents a rapid force loss, seems to take place within the first 3–4 hours after extension.

The percent relaxation of the materials included in the study is shown in Table 2. No statistical difference was found for the force decay, which at the end of 24 hours reached levels in the order of 25%.

Figure 3 presents the curve fitting and corresponding equation for a representative 24-hour relaxation curve. The equation describing the 24-hour relaxation results is $y^{-1} = 0.010 + 3.69x^{0.5}$ ($r^2 = 0.96$), whereas the initial steep component of the curve (Figure 4) is better described by the equation $y = a + bx^{0.5}$ ($r^2 = 0.98$).

DISCUSSION

The results of this study imply that force relaxation of elastics is a material-dependent parameter because size and force did not have a significant effect on varying the extent of force decay. Caution should be exercised in applying these results to elastomeric (synthetic elastic) materials. In synthetic elastics, such as elastomers, the force, which tends to retract the extended specimen to its original length, arises from the macromolecular chain entanglements, ie, interconnection of chains. On the contrary, in natural rubbers such as latex, the retracting force is because of the covalent bonding and cross-linking of chains. The major structural differences between natural rubber and synthetic elastics may account for a different long-term performance of nonlatex elastics.

Recently, a number of studies comparing the mechanical properties and relaxation characteristics of latex and nonlatex elastics have demonstrated a vastly different time-related mechanical performance of nonlatex materials. In general, nonlatex elastics have been shown to present more force decay over time than latex elastics.[8,9] It has also been proposed that various environmental factors, such as moisture and heat, could have different and probably more negative effects on synthetic elastics because of differences in structure.[9]

This study used an experimental configuration, which facilitated continuous data recording in real time and without any intervention by the operator. In the past, the force exerted at various extensions was measured with several setups such as a dynamometer. A typical experimental configuration used by several investigators involved stretching of the elastics with the aid of a custom-made frame. The elastic was periodically detached from the frame, and the force required to restretch it was recorded with a dynamometer or a tensometer.[4–6] This method allowed for the study of force decay in a controlled environment by simply immersing the whole frame in various media and controlling the environmental variables such as temperature and pH. This facilitated the opportunity to reveal the effect of several environmental factors on the mechanical properties of the elastics.

On the other hand, the method suffers from two major weaknesses: first, it fails to allow for the collection of continuous data because the force is only periodically recorded, and thus noncontinuous data is used to construct the force relaxation curves, inducing some unavoidable approximation. The second and probably more critical weakness relates to the excessive handling of the specimens and repeated extensions of the same specimen at different time intervals to record force loss. This process may induce fatigue of the material, precluding a reliable extrapolation of the extent of relaxation.

The results of this study show a remarkable decrease in the force applied by the elastic within the first 3–5 hours, whereas a 20–25% decrease was noted for the 24-hour period. An additional factor, which further diminishes the force applied with these auxiliaries, relates to the biomechanical setup formulated in the interarch application of elastics in Class II and Class III cases. Considering an elastic specimen extended from a canine to the first molar, it is evident that the functional constituent of the force in the horizontal direction varies with the cosine of the angle formed by the force vector. Thus, for a 100-g force elastic stretched as in the case of Class II pull and small sagittal dimension of archers, the angle formed is increased. For a 60°, angle the cosine is 0.5, and therefore, the horizontal constituent of the force is F cos 60° or 50 g. According to the results of this study, at the end of the 24-hour period and because of the initial steep decline in force, roughly after 3–5 hours after extension, the elastic would present 20–25% relaxation. Therefore, the force applied between the canine and first molar in the horizontal direction would be diminished to 37.5–40 g. In addition, the vertical component of the force would be high, which makes the application of interarch pull in this case undesirable, because of the associated extrusion of teeth, a fact that may be especially detrimental in hyperdivergent facial patterns.

The above discussion is indicative of the inefficiency of the system, which under specific circumstances, fails to deliver the applied load. The situation is different when the angle formed is small, for example 30°, as in the case of attaching the elastic to second molar as opposed to the first. Then the initial horizontal constituent of the force applied is 86 g and the relaxed force at the end of 3- to 4-hour period 50–60 g. To minimize relaxation, patients may be instructed to change the elastics twice daily.

Moreover, taking into account that the aging in the intraoral environment exerts potent effects on the elastic, it is expected that the relaxation would be higher and the force applied at the end of the 3- to 4-hour period further decreased. This is because the oral cavity, which includes a wide array of potent aging factors such as pH fluctuations, temperature variation, and enzymatic or microbial action, may constitute a vastly different aging profile for the material, altering its mechanical properties. In general, in vitro approaches in assessing the mechanical performance of biomaterials have been proven to underestimate the extent and severity of effects induced during intraoral aging in alloys, plastics, and ceramics.[10,11]

In general, force relaxation of elastics has been studied in the literature through numerous setups and in many environments and protocols involving dry or wet testing states including water, artificial saliva, or fluoride media,[12] with varying temperatures, decreasing or steady force application,[13] and acidic or neutral pH.[14,15] In vivo aged elastomerics, on the other hand, have shown a pattern involving adsorption of proteinaceous species, which later become calcified.[11] The interaction of multifactorial aging variables in the oral cavity has not been elucidated and remains unknown. Simultaneous variation of temperature, pH, and cyclic mechanical loads, may have different effect than the each parameter isolated.

Also, water has been found to induce plasticization through release of substances from the elastic, absorption of water molecules, and swelling of the material, leading to lowering of the glass transition temperature and free energy for crack initiation. Lipid absorption in the oral cavity effectively alters the reactivity of the material, introducing nuclei for calcification and increasing water sorption.[11] This study showed relatively high and probably clinically important 24-hour force decay, although it was carried out in an in vitro dry environment. The aforementioned environmental factors, such as moisture, temperature variation, or microbial activity, could not be evaluated in the present experimental setup.

Further studies assessing the relaxation and force levels of intraorally aged elastics should be performed to estimate the extent of relaxation phenomena in clinical conditions.

CONCLUSIONS

- Latex elastics show force relaxation in the order of 25%, which consists of an initial high slope component and a latent part of decreased rate.
- Most of the relaxation was shown to occur within the first 3–5 hours after extension, regardless of size, manufacturer, or force level of the elastic.
- The empirical rule of ‘‘3’’ indicating that the reported force level is achieved on extending the elastic three times its diameter, does not apply to all cases and shows remarkable variation, ranging from 2.7 to five.

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