Original Article

A Comparison of Dynamic and Static Testing of Latex and Nonlatex Orthodontic Elastics

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Abstract: The purpose of this study was to determine the effects of repeated stretching (cyclic testing) and static testing on the force decay properties of two different types of orthodontic elastics from a single supplier. Samples of American Orthodontics'® 0.25 inch, 4.5 oz (6.35 mm, 127.5 g) latex and nonlatex elastics were used and a sample size of 12 elastics per group was tested. Static testing involved stretching the elastics to three times marketed internal diameter (19.05 mm) and measuring force levels at intervals over 24 hours. Cyclic testing used the same initial extension but cycled the elastics an additional 24.7 mm to simulate extension with maximal opening in the mouth. Both types of elastic had similar initial forces that were statistically below the marketed force (122 and 118 g for latex and nonlatex elastics, respectively) at three times marketed internal diameter. Cyclic testing caused significantly more force loss and this difference occurred primarily within the first 30 minutes. For statically tested elastics the percentage of initial force remaining at 4, 8, and 24 hours was 87%, 85%, 83%, and 83%, 78%, 69% for latex and nonlatex elastics, respectively. For cyclically tested elastics the percentage of initial force remaining at 4, 8, and 24 hours was 77%, 76%, 75%, and 65%, 63%, 53% for latex and nonlatex elastics, respectively. (*Angle Orthod* 2003;73:181–186.)

Key Words: Elastomer; Natural rubber latex; Cyclic testing; Force decay; Force generation

INTRODUCTION

Although there are multiple surveys of natural rubber latex (latex) orthodontic elastics and other synthetic elastomeric materials (ie, elastic ligatures, elastomeric chain), there is limited research on synthetic (nonlatex) orthodontic elastics. Russell et al[1] recently published an in vitro assessment of the mechanical properties of latex and nonlatex elastics that provided some insight into these products' behavior. The latex and nonlatex elastics were not similar in their behavior. Furthermore, force delivery over time varied with the manufacturer.

The majority of the orthodontic elastics on the market are latex elastics. Since the early 1990s synthetic products have been offered on the market for latex-sensitive patients and are sold as nonlatex elastics. There is limited information on the risk that latex elastics may pose to patients. Some have estimated that 0.12–6% of the general population and 6.2% of dental professionals have hypersensitivity to latex protein.[2] There are some reported cases of adverse reactions to latex in the orthodontic population but these are very limited to date.[3,4] Although the risk is not yet clear, it would still be inadvisable to prescribe latex elastics to a patient with a known latex allergy.

The most recent survey of latex elastics was written by Kanchana et al.[5] A number of different types of elastics were tested and extension and force information was provided in the results. The elastics were tested statically and one of the recommendations was that future studies look at the effect of repeat stretching. Liu et al[6] studied the effect of cycling on latex elastics and found that there was more force loss with cyclic testing but the effect was not statistically different beyond 200 cycles.

The purposes of this study were to determine the differences between the latex and nonlatex orthodontic elastics from one company regarding force production and force

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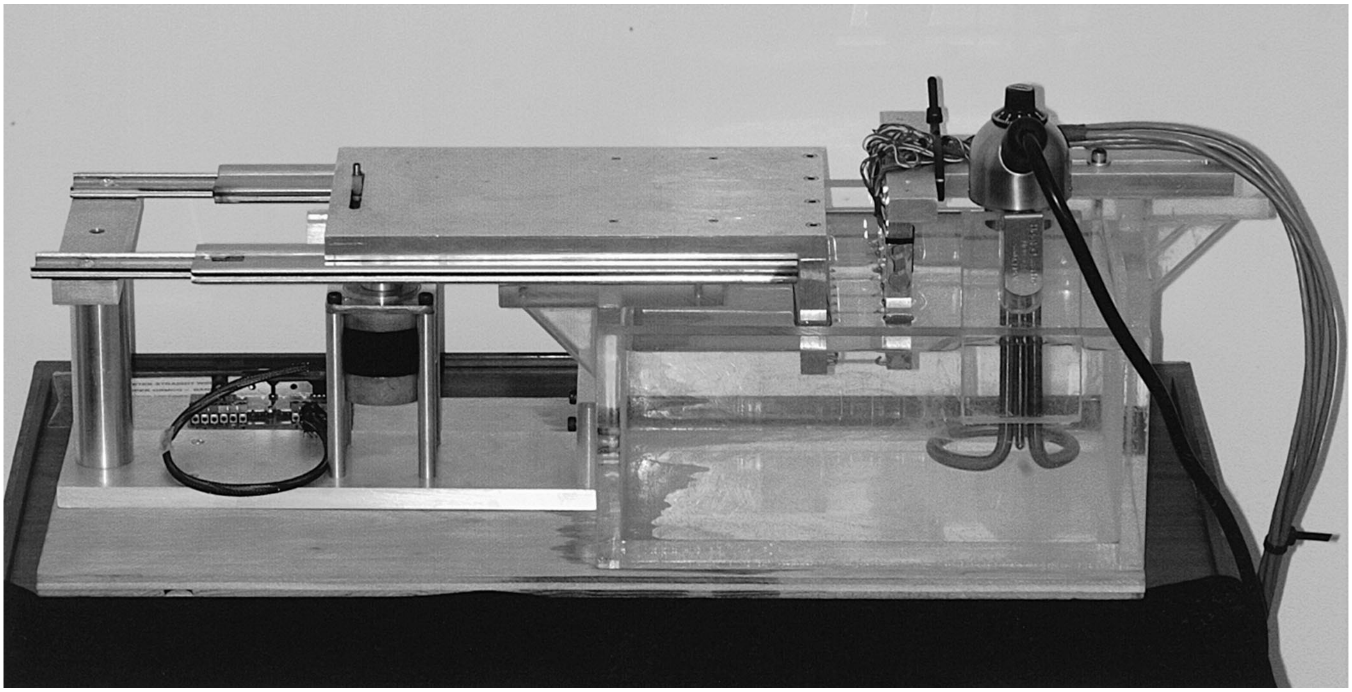

FIGURE 1. Elastic testing apparatus.

decay over time and to determine the differences between static and cyclic testing of these same elastics. This knowledge will allow orthodontists to assess the inherent forces generated by these different products at different times and should help to improve treatment delivery for interarch mechanics.

MATERIALS AND METHODS

Testing apparatus

The testing apparatus was designed by the authors and custom-made at the Department of Mechanical Engineering at the University of Alberta (Figures 1 and 2). The design allowed us to test six elastics submerged in a 37°C distilled water bath. Temperature was maintained by a submersible heater (George Ulanet Co. Model 324 Heet-O-Matic) with an internal thermostat (accuracy ± 0.6°C). The force-measuring component of the apparatus consisted of a series of six binocular beams with strain gauges (in full bridge configuration). These beams have been used in the past to measure forces similar to what we had expected.[7] Each beam was calibrated independently to determine its accuracy and sensitivity.

The elastics were attached to hooks and one end (left side of Figures 1 and 2) was able to move freely on a set of runners with bearings, whereas the force-measuring end (right side of Figure 2) was held securely. A stepper motor (Nema 23 5-wire high torque) was used to cycle the elastics when tested dynamically and the system was locked at a set length for static testing. An adjustable pin and slot mechanism attached to the motor's shaft allowed us to adjust the cycling amplitude. The stepper motor was controlled by software supplied with the motor by Steppercontrol.com (Mill-Shaf Technologies Inc, Yadkninville, NC) and run with a laptop computer and an A-200 stepper motor controller from Steppercontrol.com. Output from the binocular beams was sent to a Hewlett-Packard E1401A data acquisition system and a custom-written LabVIEW (National Instruments Inc) software program on a desktop personal computer.

Pilot study and error analysis

A pilot study was completed to look at sample variability and testing apparatus error. Six 0.25 inch, 4.5 oz (6.35 mm, 127.5 g) latex and nonlatex elastics were tested in each group. The samples were from the same supplier (American Orthodontics Inc®, Sheboygan, Wis). Results from this study were used to determine sample sizes for further study and to investigate error in the testing apparatus.

Sample size calculations were performed using Mintab for Windows and used a sample size calculation formula that required input of estimated standard deviation, desired power, and desired minimum detectable difference.[8] A maximum standard deviation of 7% was observed in force decay values in the pilot study and was used in the calculations. Eighty percent power was used, and a minimum desired detectable difference chosen was 10%. The formula also assumed that four groups would be compared in the study. The result of these calculations was a required sample size of 12 elastics.

Individual binocular beams were calibrated by loading

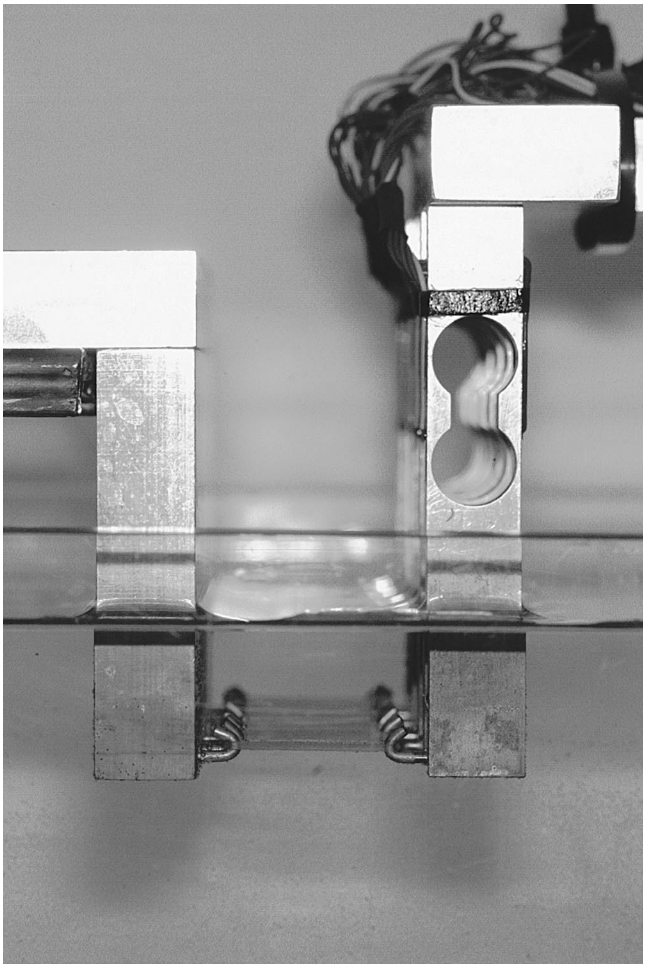

FIGURE 2. View of elastics in the testing apparatus.

them with 0, 10, 20, 50, 100, 200, and 250 g loads and measuring output voltage. R^2 values were 0.999 for all six of the beams used indicating a nearly perfect linear relationship between the load applied and voltage output.

Error of the testing apparatus was determined by loading each testing beam with a known load and determining the variation over an eight-hour period. The error in the system was ±3% for a fixed 100 g load.

Study design

A sample size of 12 elastics per group was used for this study. Samples were obtained close to the testing time from the manufacturer and were within their expiration dates. The elastics were stored as recommended in sealed bags in a cool and dark environment. Any distance measurements that were required were taken using electronic digital calipers with a marketed accuracy of ±0.02 mm (Lee Valley Tools Ltd, Item #88N6207, Ottawa Ontario).

Two materials were tested under two different testing methods yielding four test groups. The elastics were compared by testing six elastics at one time with a mixture of the two types of elastic tested at the same time. Latex and nonlatex elastics (0.25 inch, 4.5 oz [6.35 mm, 127.5 g]) from American Orthodontics® were either cycled or statically tested. Both groups were initially stretched to three times the marketed internal diameter (19.05 mm). The static groups were held at this length, whereas the cycled groups were stretched an additional 24.7 mm, with a cycle duration of one second and a frequency of one cycle/min. The cycling distance was chosen using data provided by a computer model of the masticatory system that has been created by the University of British Columbia,[9] to approximate the change in distance from the upper right canine to the lower right first molar with wide opening. This distance changed 24.7 mm with a maximal opening of 50 mm.

Forces generated by the elastics were recorded immediately after they were placed in the apparatus and at 0.5, 1, 1.5, 2, 4, 8, 16, and 24 hours. Forces were always measured at three times marketed internal diameter. Another 12 elastics per type (24 total) were tested to determine the initial forces generated when stretched to two times internal diameter (0.50 inch or 12.7 mm) to allow for comparisons of initial force values at this stretched distance.

RESULTS

A summary of initial forces generated by American Orthodontics'® 0.25 inch, 4.5 oz (6.35 mm, 127.5 g) latex and nonlatex elastics when stretched to two and three times the marketed internal diameter (12.7 and 19.05 mm) is presented in Table 1 along with descriptive statistics for both extension distances. Both types of elastics had similar standard deviations and had relatively large ranges of initial force. Paired *t*-tests were done using SPSS for Windows (SPSS Inc) and found that both the latex ($P < .01$) and nonlatex ($P < .0001$) elastics differed statistically from the marketed force level of 4.5 oz (127.5 g).

Figure 3 displays the decay in force levels over the 24-hour testing period in the four groups. The changes that are seen represent the changes in percent of initial force. All groups showed force decay over time with greatest force loss in the first 30 minutes. Table 2 shows the mean percent initial force along with descriptive statistics for the different elastic materials and testing methods.

SPSS for Windows (SPSS Inc) was used to compare the groups, and a multiple comparison ANOVA was done to determine statistically significant differences between the materials and testing methods. The difference between materials was not statistically significant early in testing but became significant at eight hours into testing $P < .0001$. The difference between cycling and static testing was significant at 30 minutes ($P < .0001$). Percentage of initial force remaining at the 24-hour force recordings were 75% for the latex cycled elastics compared with 83% for the statically tested latex elastics. The nonlatex elastics had per-

TABLE 1. Initial Forces and Descriptive Statistics at Two Extensions[a]

American Orthodontics 0.25 inch (6.35 mm) 4.5 oz (127.5 g)	2 × Internal Diameter (0.5 inch, 12.7 mm) Force (g)			3 × Internal Diameter (0.75 inch, 19.05 mm) Force (g)		
	N	Mean (SD)	Range	N	Mean (SD)	Range
Latex	12	53.74 (6.93)	43.81–64.66	24	122.22 (9.21)*	106.91–141.43
Nonlatex	12	55.41 (7.02)	46.88–69.44	24	118.29 (6.64)**	104.51–130.00

[a] Paired *t*-test comparisons used to compare actual forces generated with marketed forces.
* Significantly different from manufacturer's value at $P < .01$.
** Significantly different from manufacturer's value at $P < .0001$.

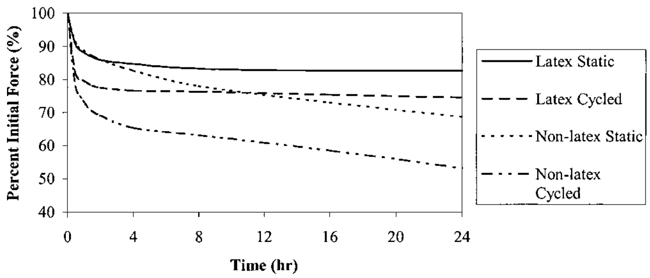

FIGURE 3. Mean percent initial force over time grouped for elastic material and testing method.

cent initial force remaining at 24 hours of 53% for the cycled group compared with 69% for the static group.

DISCUSSION

The testing methods used in this study attempted to simulate interarch use of orthodontic elastics in a laboratory setting. Although water-bath testing is probably the most realistic medium for large-scale testing of orthodontic elastomers, this medium may only be adequate for short-term testing.[10] The dynamic testing scenario estimated distance changes with wide opening from a model based on averages.[9] The distances used may have been on the higher side of average clinical distances. But others have used similar estimations in the past for interarch mechanics and the values used were within the ‘‘clinical ranges’’ used by Liu et al[6] and Bishara and Andreasen.[11]

Most studies have tested orthodontic elastics in a static environment. Cyclic testing of orthodontic elastics, whether latex or nonlatex, led to significantly more force loss in this study. The nonlatex elastics were more affected than their latex counterparts were. This could have been because of more chain slippage at the molecular level due to repeated stretching, because of extension beyond the elastic limit of the product or a combination of both. Cycling of the elastics also caused a larger decrease in force early in testing but the force decay rate was similar to that of the statically tested elastics after the first hour. This can be seen by the slopes of the two materials in Figure 3 that are the same after one hour even though the values are different. These findings were similar to what was observed by Liu et al and earlier studies.[6,12] Liu et al reported that after 200 cycles

TABLE 2. Grouped Data for Percent of Initial Force Over Time and Descriptive Statistics

			% Initial Force			
Time (h)	Material	Testing Method	Minimum	Maximum	Mean	SD
.5	Latex	Cycled*	78.26	85.02	81.46	1.86
		Static*	88.73	91.74	90.42	0.75
	Nonlatex	Cycled*	74.95	80.20	77.53	1.52
		Static*	89.41	93.18	91.28	1.24
1.0	Latex	Cycled*	77.60	84.37	79.65	1.70
		Static*	85.65	89.18	88.14	1.09
	Nonlatex	Cycled*	60.65	78.38	73.12	6.04
		Static*	86.92	91.03	88.87	1.34
1.5	Latex	Cycled*	75.69	82.20	78.17	1.69
		Static*	84.29	88.24	86.77	1.26
	Nonlatex	Cycled*	57.91	76.57	70.43	6.15
		Static*	85.22	88.99	87.17	1.12
2.0	Latex	Cycled*	74.49	82.28	77.58	1.85
		Static*	82.96	87.47	85.92	1.43
	Nonlatex	Cycled*	57.13	74.91	69.04	5.81
		Static*	83.95	87.89	85.96	1.18
4.0	Latex	Cycled*	73.13	80.88	76.56	2.20
		Static*	82.86	86.54	84.72	1.26
	Nonlatex	Cycled*	54.04	70.51	65.32	5.11
		Static*	80.17	84.88	82.70	1.32
8.0	Latex**	Cycled*	72.59	82.11	76.34	2.60
		Static*	81.03	84.95	83.29	1.17
	Nonlatex**	Cycled*	50.15	67.56	63.08	5.01
		Static*	73.06	80.22	78.04	2.13
16.0	Latex**	Cycled*	70.90	80.60	75.37	2.72
		Static*	80.62	85.97	82.65	1.71
	Nonlatex**	Cycled*	50.01	62.66	58.48	4.67
		Static*	65.37	81.10	73.02	4.57
24.0	Latex**	Cycled*	70.99	79.66	74.55	2.91
		Static*	80.37	87.39	82.74	1.90
	Nonlatex**	Cycled*	44.98	57.96	53.16	4.31
		Static*	58.23	78.09	68.73	6.12

* Statistically significant difference between testing methods $P < .0001$.
** Statistically significant difference between materials $P < .0001$.

there was no significance to further cycling regarding force decay. There was some recovery of forces generated by the cycled elastics in the study by Liu et al after repeated stretching, but this study was unable to assess this phenomenon because of the testing methods that spread the cycling throughout the test period.

Although the distance the elastics were cycled was not arbitrary, the choice of one cycle per minute was relatively arbitrary and was chosen by the authors to reflect a balance between the higher frequency of opening seen during chewing and the lower frequency seen at other times. Cycles were spread out in an attempt to better simulate the conditions in the mouth of an orthodontic patient.

On the basis of results from this study and those of Liu et al,[6] cyclic testing of orthodontic elastics used for interarch mechanics should be a component of material testing to get a clearer picture of actual forces being delivered over time. The difference in percentage of decrease from initial force, which could be attributed to cycling, was 15.6% in the nonlatex elastics and 8.2% for the latex elastics during the 24-hour test period. The different effects seen for the two materials was further support for cyclic testing of new materials because some materials may be better than others at withstanding repeated stretching. With further testing, it may be possible to determine a relatively consistent percentage of initial force loss that could be used as an estimate for cycling of various materials. This would allow for broader testing without the difficulties posed by a cyclic testing apparatus and the expense of apparatus design and fabrication.

The force measurement system we used was new but similar to that used by Russell et al.[1] A significant advantage of the systems used in this study, and the study by Russell et al, was the ability to test over time without removing the samples for hand measurement or Instron testing. One of the conclusions reached by Russell et al was that ''the mechanical properties of nonlatex elastics cannot be assumed to be—and indeed are not—the same as those of latex elastics.''[1] Russell et al found differences between the GAC® nonlatex and Masel® nonlatex products. The GAC® elastics retained approximately 60% of initial force after 24 hours, whereas the Masel® elastics faired better retaining approximately 75% of their initial force. The Masel® nonlatex elastics maintained forces similar to the latex elastics studied in their experiment. The results of this study are similar because they indicate a difference between the latex and nonlatex products we tested but the results were closer to the results seen for the GAC® elastics in the study by Russell et al. This study found that American Orthodontics'® latex elastics maintained higher force levels over time with 83% of initial force remaining at 24 hours vs 69% of initial force remaining at 24 hours for the nonlatex elastics when tested statically. The results showed a continuing force loss for the nonlatex elastics that became statistically different from the latex elastics after eight hours of testing.

This study only compared one company's latex elastic with its nonlatex elastic. In addition, only one size and force level of elastic was studied. But the results should allow for more educated use of American Orthodontics'® latex and nonlatex elastics. Similar to the study by Russell et al,[1] the results indicate a significant difference between the two materials. Different processes may be causing the forces to decline in the elastics and these differences are likely related to differences in the structure of the polymers involved. Because composition of nonlatex elastics is proprietary, speculation is all that is possible. The nonlatex elastics, as a synthetic elastomer, may rely more on molecular entanglement for structural integrity rather than covalent cross-linking that is present in natural rubber latex products.[1] This structural difference may result in the poorer long-term performance of the nonlatex elastics and could allow other environmental factors such as moisture and heat to have different and more negative effects.

What amount of force degradation is significant? There is no clear answer to this question, and it may depend on the magnitude of the force and the precision desired by the clinician. There is no consensus in the literature but others have used a 10% difference as a measure that could be clinically significant when looking at elastomeric chain.[13] Ten percent is probably a reasonable number and should be kept in mind when discussing the results above and relating them to the clinical setting.

The first clinical note is that there was variability within the same samples. Standard deviations were similar to those seen in recent studies.[1,5] Forces generated at two and three times the marketed internal diameter were measured and the results were different from previous studies. Contrary to what Bales reported, this study found that at two times the marketed internal diameter, the elastics generated forces well below the marketed force.[14] Other more recent studies have also observed that the majority of elastics tested produced higher than marketed forces at three times the marketed internal diameter.[1,5] Why these results differ from previous studies is not entirely clear, but it could indicate that there are differences between suppliers or batches that could exist. None of American Orthodontics'® products were tested in the studies referenced above, so direct comparisons are limited.

Clinical use of elastics would ideally start with a measurement of the attachment points and selection of the elastic that would require stretching to three times internal diameter to extend over that distance. It would be advisable to assess a sample of the elastics purchased to determine a range of forces because a product may not perform precisely as specified by the manufacturer. A second clinical point is that with these latex elastics approximately 25% of force was lost in 24 hours, with the majority of force loss occurring in the first hour. The nonlatex elastics lost nearly 50% of their force over the 24-hour period. The nonlatex elastics reached 75% of initial force in the first hour, which was where the latex elastics were after 24 hours. The nonlatex elastics had approximately 63% of their force remaining at eight hours, which is what may occur if a patient were to change elastics three times daily. Clinically, the decision will have to be made about whether to start with a higher force than deemed necessary or end up with a lower force than desired after a very short time in the mouth. Further study is needed using different brands of latex and nonlatex elastics along with different sizes and force levels. This would help to determine whether the results of this study are comparable to what might be seen on a larger scale among different manufacturers.

CONCLUSIONS

1. American Orthodontics'® latex elastics (0.25 inch, 4.5 ox, 6.25 mm, 127.5 g) retained significantly more force over time than their nonlatex equivalents.
2. Cyclic testing of orthodontic elastics caused significantly more force loss than static testing but this effect was seen early in testing and did not change the rate of force decay after this.
3. Because of higher rates of force loss that continued throughout testing, it is more important that nonlatex elastics be changed at regular intervals not exceeding 6–8 hours.
4. Because of variability in force delivery, it is advisable for practitioners to test a sample of their elastics before using them or purchasing large quantities to ensure that the force levels are in the expected range.

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